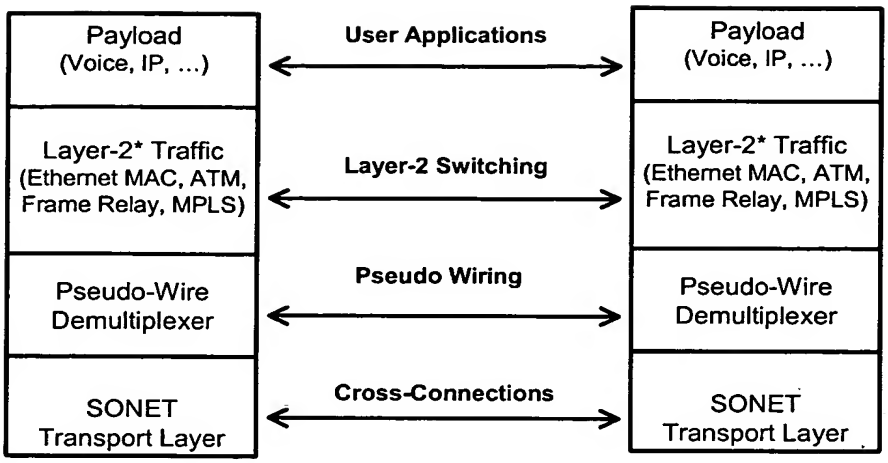



Figure 1

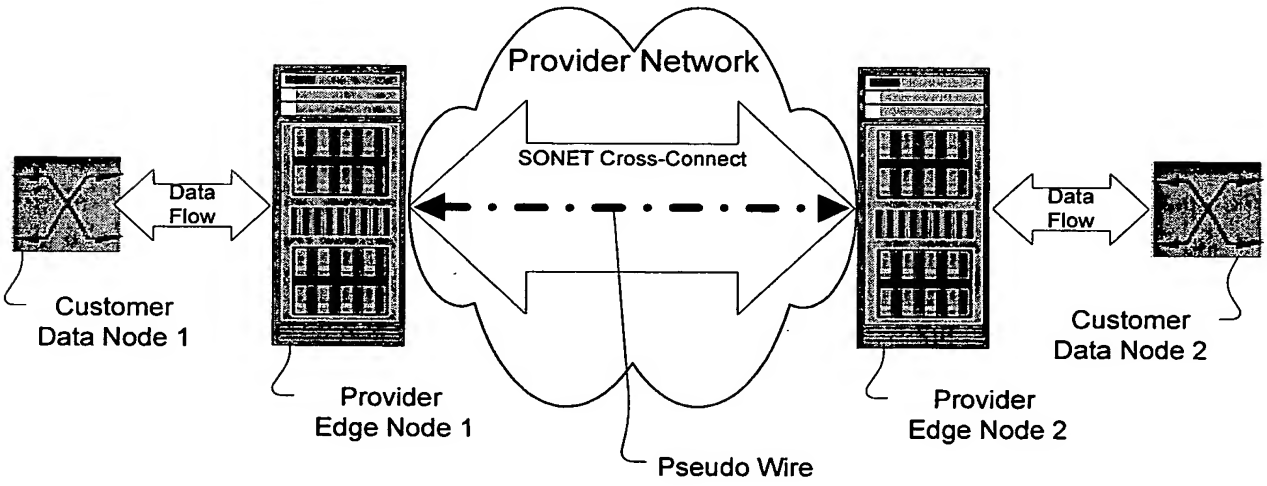



Figure 2

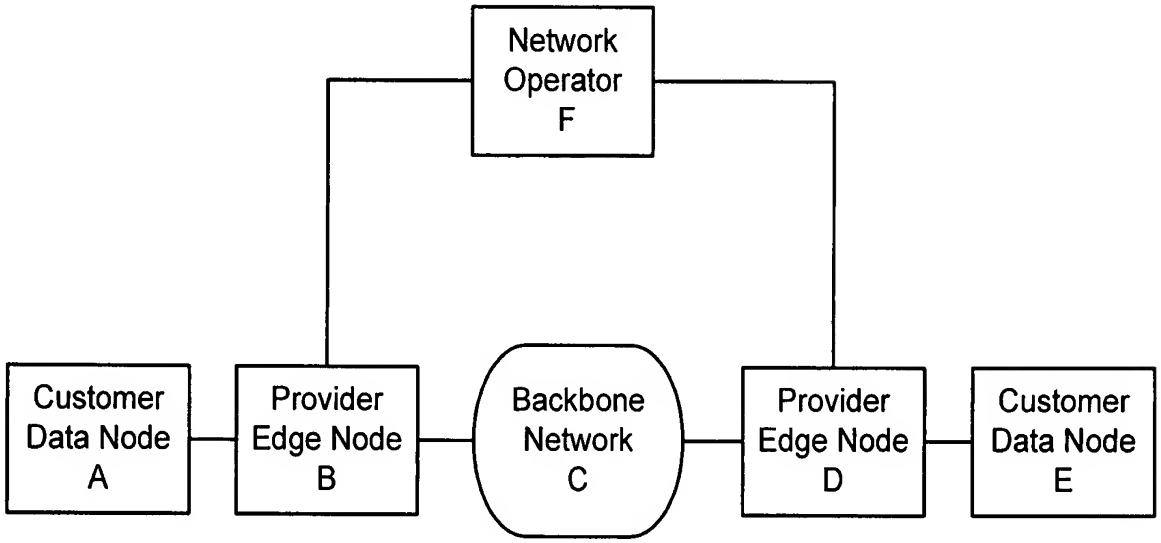

Network
Operator
F
Customer
Data Node
A
Provider
Edge Node
B
Backbone
Network
C
Provider
Edge Node
D
Customer
Data Node
E

Figure 3

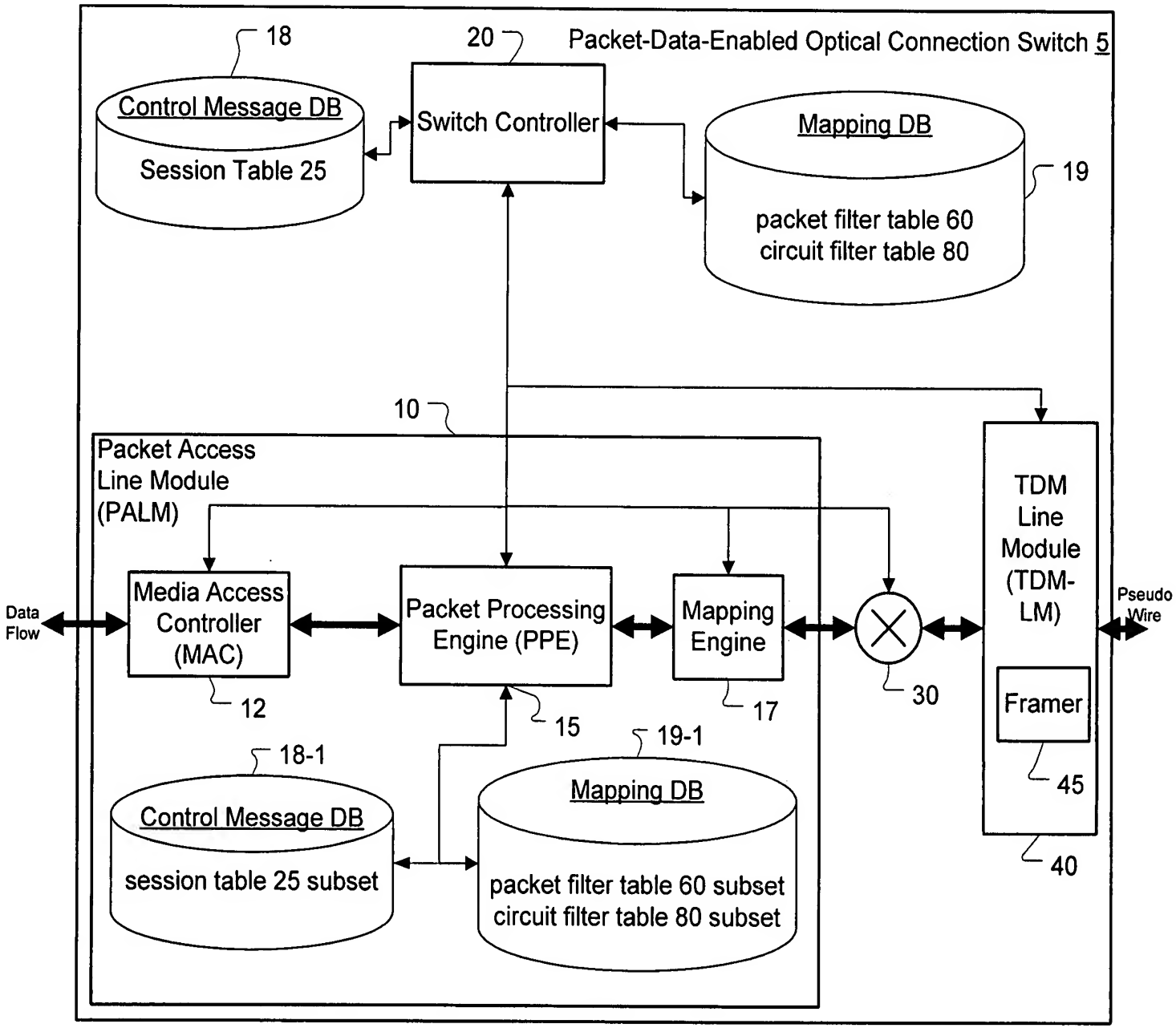

18
20
Packet-Data-Enabled Optical Connection Switch 5
Control Message DB
Session Table 25
Switch Controller
Mapping DB
19
packet filter table 60
circuit filter table 80
10
Packet Access
Line Module
(PALM)
TDM
Line
Module
(TDM-
LM)
Data
Flow
Media Access
Controller
(MAC)
Packet Processing
Engine (PPE)
Mapping
Engine
Pseudo
Wire
12
15
17
30
Framer
45
40
18-1
19-1
Control Message DB
session table 25 subset
Mapping DB
packet filter table 60 subset
circuit filter table 80 subset

Figure 4

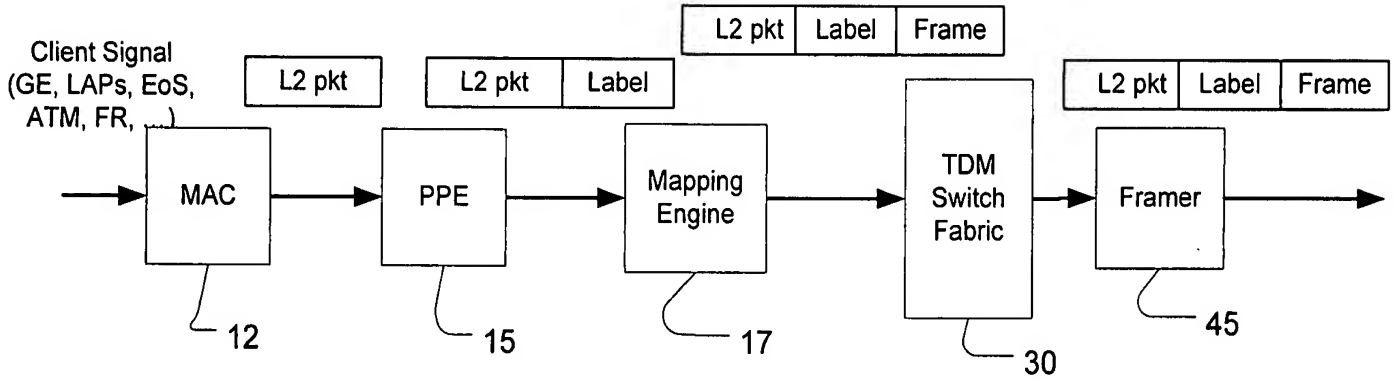



Figure 5

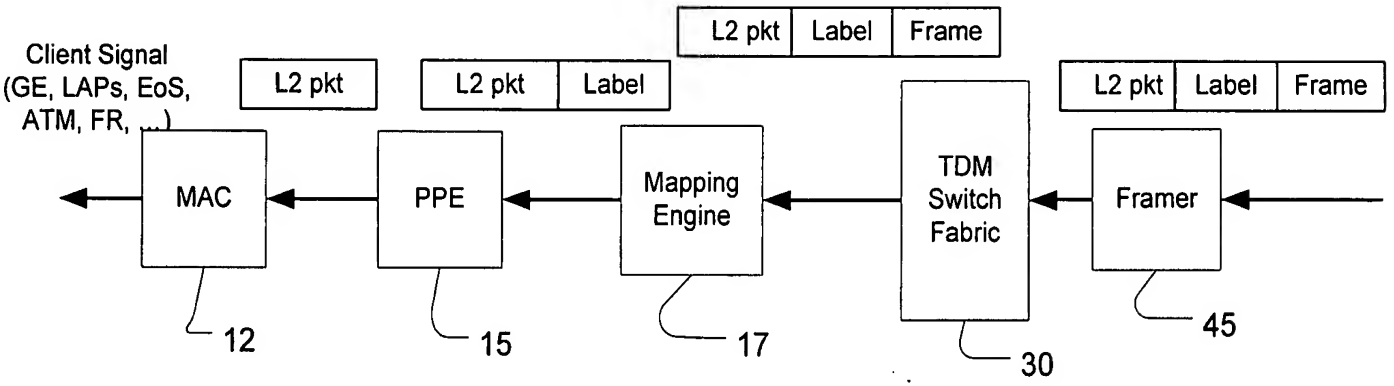



Figure 6

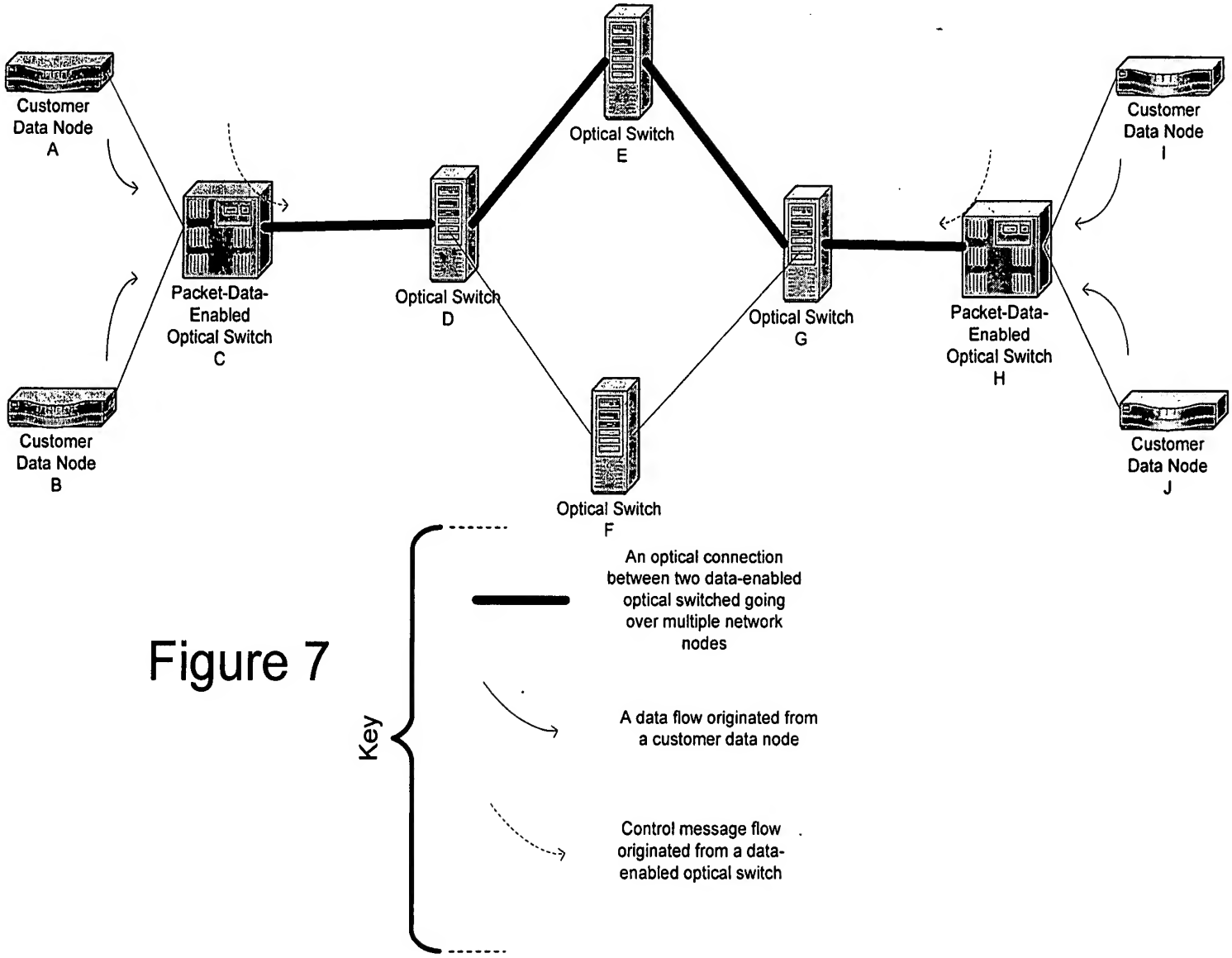

Customer Data Node A
Customer Data Node B
Packet-Data-Enabled Optical Switch C
Optical Switch D
Optical Switch E
Optical Switch F
Optical Switch G
Packet-Data-Enabled Optical Switch H
Customer Data Node I
Customer Data Node J
Key
An optical connection between two data-enabled optical switched going over multiple network nodes
A data flow originated from a customer data node
Control message flow originated from a data-enabled optical switch

Figure 7

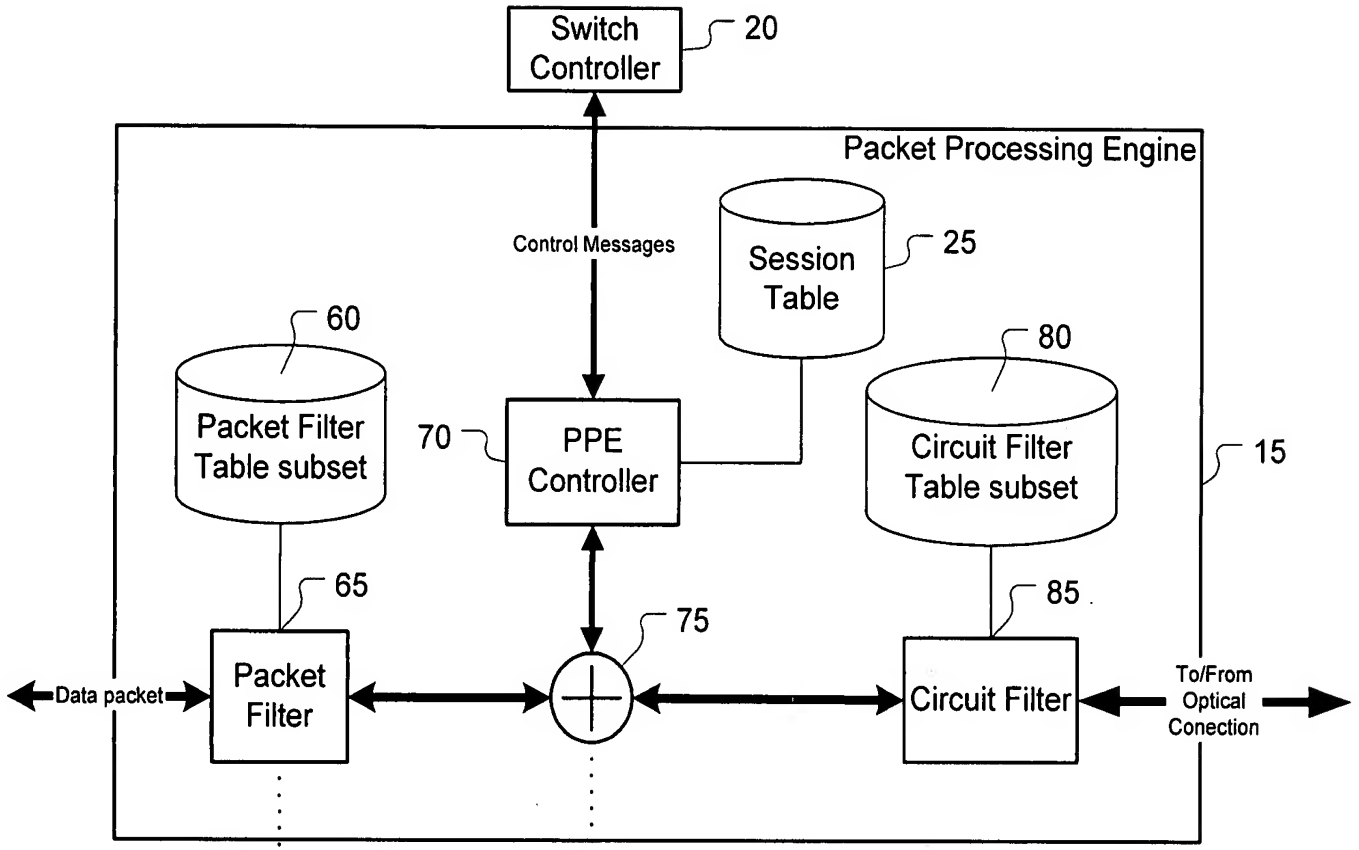
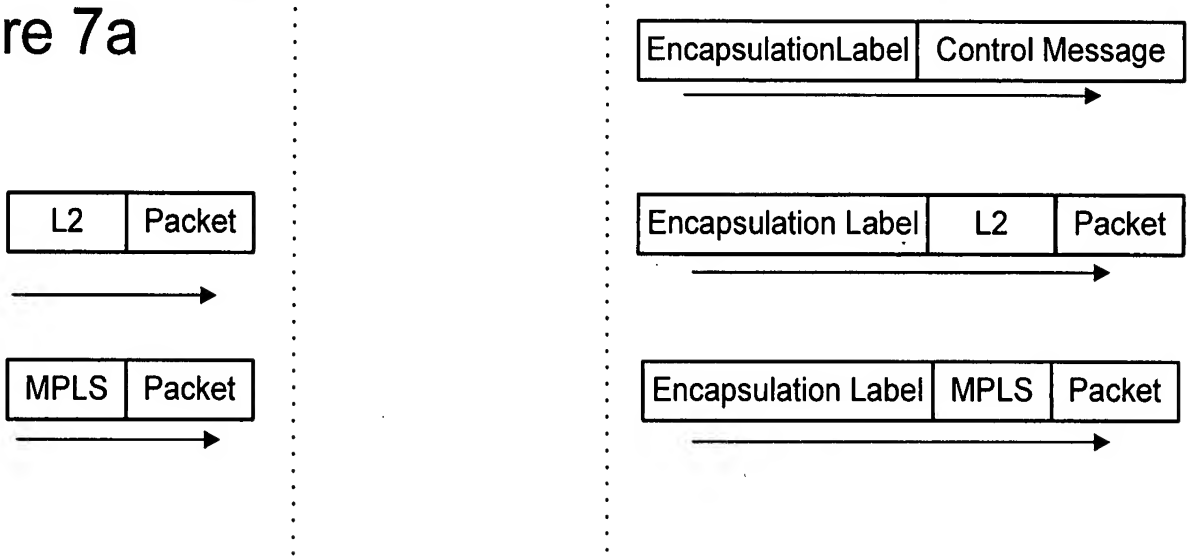

Switch Controller
20
Packet Processing Engine
Control Messages
Session Table
25
60
Packet Filter Table subset
70
PPE Controller
80
Circuit Filter Table subset
15
65
75
85
Data packet
Packet Filter
Circuit Filter
To/From Optical Conection

Figure 7a


EncapsulationLabel
Control Message
L2
Packet
Encapsulation Label
L2
Packet
MPLS
Packet
Encapsulation Label
MPLS
Packet

60

| PACKET FILTER TABLE | | | | |
|---|---|---|---|---|
| PACKET FILTER (DATA INTERFACE, LABEL) | OUTGOING OPTICAL CONNECTION | ENCAPSULATION LABEL | FILTER PRIORITY | GUARANTEED QOS |
| PACKET FILTER-1 (PORT 1, ETHERNET VLAN 100) | SONET VCG NUMBER 3 | MPLS LABEL 10000 | 3 | X |
| PACKET FILTER-2 (PORT 5, ATM VCI/VPI 12/45) | SONET VCG NUMBER 3 | MPLS LABEL 20000 | 3 | Y |
| PACKET FILTER-3 (PORT 2, FR DLCI 900) | OPTICAL INTERFACE 1 | MPLS LABEL 500 | 3 | Z |
| PACKET FILTER-4 (PORT 1, MPLS LABEL 10000) | SONET VCG NUMBER 5 | MPLS LABEL 10001 | 1 | S |

Figure 7b

80

| CIRCUIT FILTER TABLE | | | |
|---|---|---|---|
| CIRCUIT FILTER (OPTICAL CONNECTION, LABEL) | OUTGOING DATA INTERFACE | OVERWRITTEN LABEL | GUARANTEED QOS |
| CIRCUIT FILTER-1 (SONET VCG 3, LABEL 20000) | DATA PORT 1 | ETHERNET VLAN 200 | X |
| CIRCUIT FILTER-2 (SONET VCG 3, LABEL 20001) | DATA PORT 2 | ATM VCI/VPI 23/56 | Y |
| CIRCUIT FILTER-3 (OPTICAL INTERFACE 1, LABEL 300) | DATA PORT 1 | NONE | Z |
| CIRCUIT FILTER-4 (SONET VCG 5, LABEL 12000) | DATA PORT 23 | FRAME RELAY DLCI 200 | S |
| CIRCUIT FILTER-5 (SONET VCG 3, LABEL 3) | HOST INTERFACE | NONE | T |

Figure 7c

25

| SESSION TABLE | | | |
|---|---|---|---|
| SESSION (CONTROL MESSAGE ID) | OUTGOING OPTICAL CONNECTION | ENCAPSULATION LABEL | GUARANTEED QOS |
| SESSION 1 (TCP SRC PORT 1345) | SONET VCG NUMBER 3 | MPLS LABEL 3 | X |
| SESSION 2 (TCP SRC PORT 3456) | SONET VCG NUMBER 3 | MPLS LABEL 3 | Y |
| SESSION 3 (UDP PORT 1998) | OPTICAL INTERFACE 1 | MPLS LABEL 10000 | Z |

Figure 7d

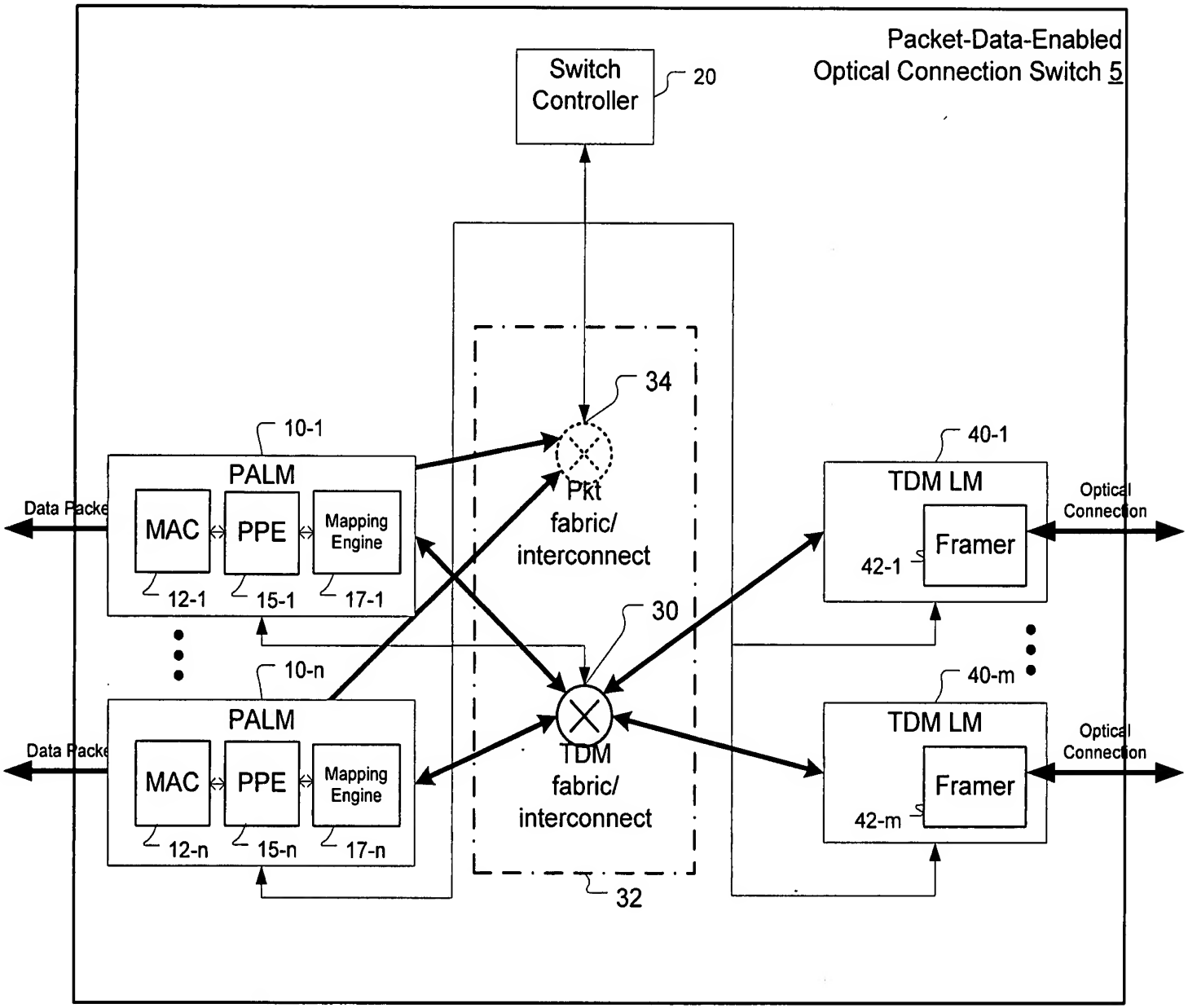

Packet-Data-Enabled
Optical Connection Switch 5
Switch Controller
20
34
10-1
PALM
MAC
PPE
Mapping Engine
12-1
15-1
17-1
Pkt fabric/ interconnect
30
10-n
PALM
MAC
PPE
Mapping Engine
12-n
15-n
17-n
TDM fabric/ interconnect
32
40-1
TDM LM
Framer
42-1
Optical Connection
40-m
TDM LM
Framer
42-m
Optical Connection

Figure 8

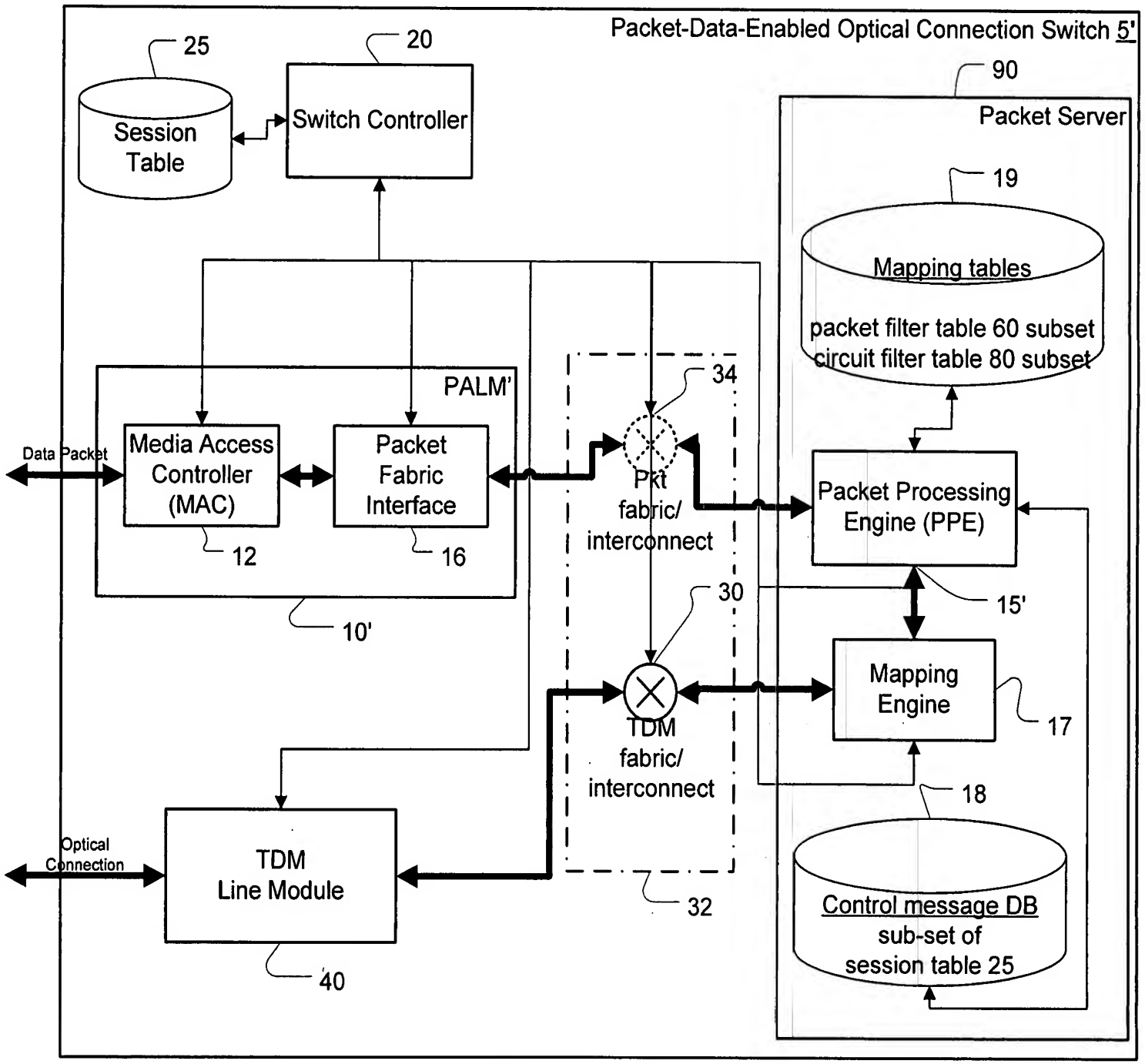

Packet-Data-Enabled Optical Connection Switch 5'
25
Session Table
20
Switch Controller
90
Packet Server
19
Mapping tables
packet filter table 60 subset
circuit filter table 80 subset
PALM'
Media Access Controller (MAC)
12
Packet Fabric Interface
16
10'
Data Packet
34
Pkt fabric/ interconnect
Packet Processing Engine (PPE)
15'
30
Mapping Engine
17
TDM fabric/ interconnect
18
Optical Connection
TDM Line Module
40
32
Control message DB
sub-set of
session table 25

Figure 9

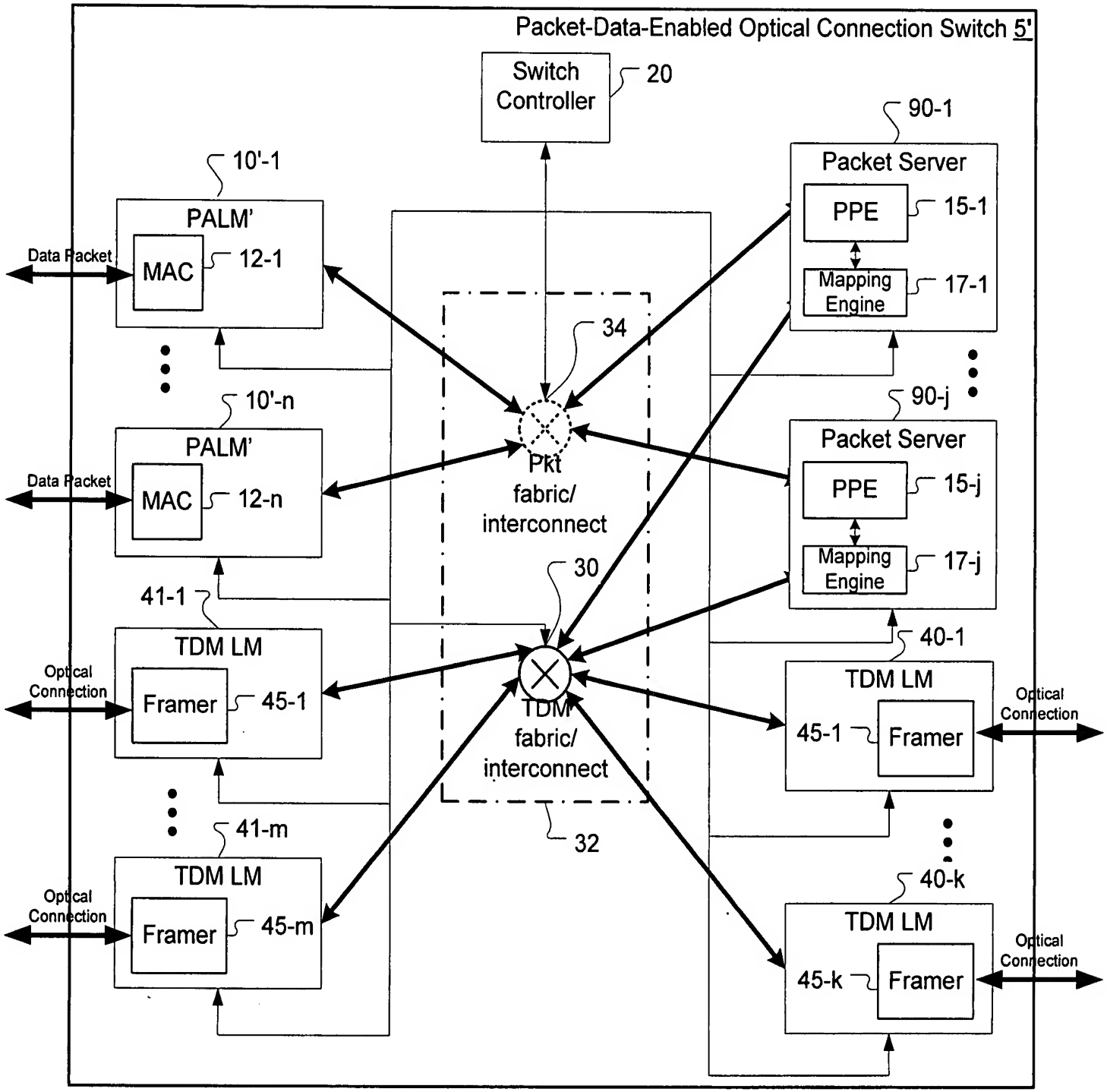

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
10'-1
PALM'
MAC
12-1
Data Packet
34
10'-n
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
PALM'
MAC
12-n
Data Packet
Pkt fabric/ interconnect
30
41-1
TDM LM
Framer
45-1
Optical Connection
40-1
TDM LM
45-1
Framer
Optical Connection
TDM fabric/ interconnect
32
41-m
TDM LM
Framer
45-m
Optical Connection
40-k
TDM LM
45-k
Framer
Optical Connection

Figure 10

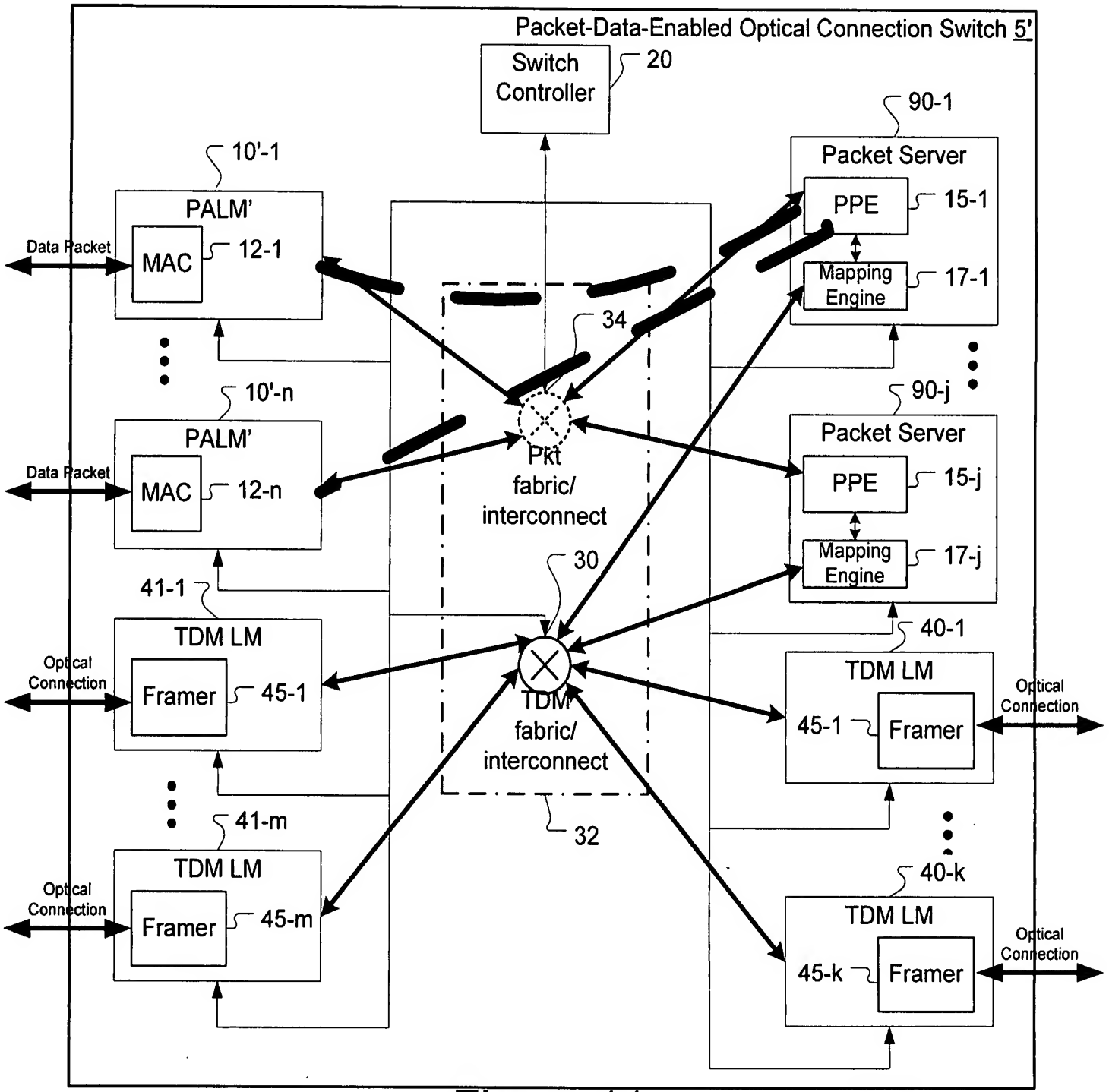

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
10'-1
PALM'
MAC
12-1
Data Packet
34
10'-n
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
PALM'
MAC
12-n
Data Packet
Pkt fabric/ interconnect
30
41-1
TDM LM
Framer
45-1
Optical Connection
40-1
TDM LM
45-1
Framer
Optical Connection
TDM fabric/ interconnect
32
41-m
TDM LM
Framer
45-m
Optical Connection
40-k
TDM LM
45-k
Framer
Optical Connection

Figure 11

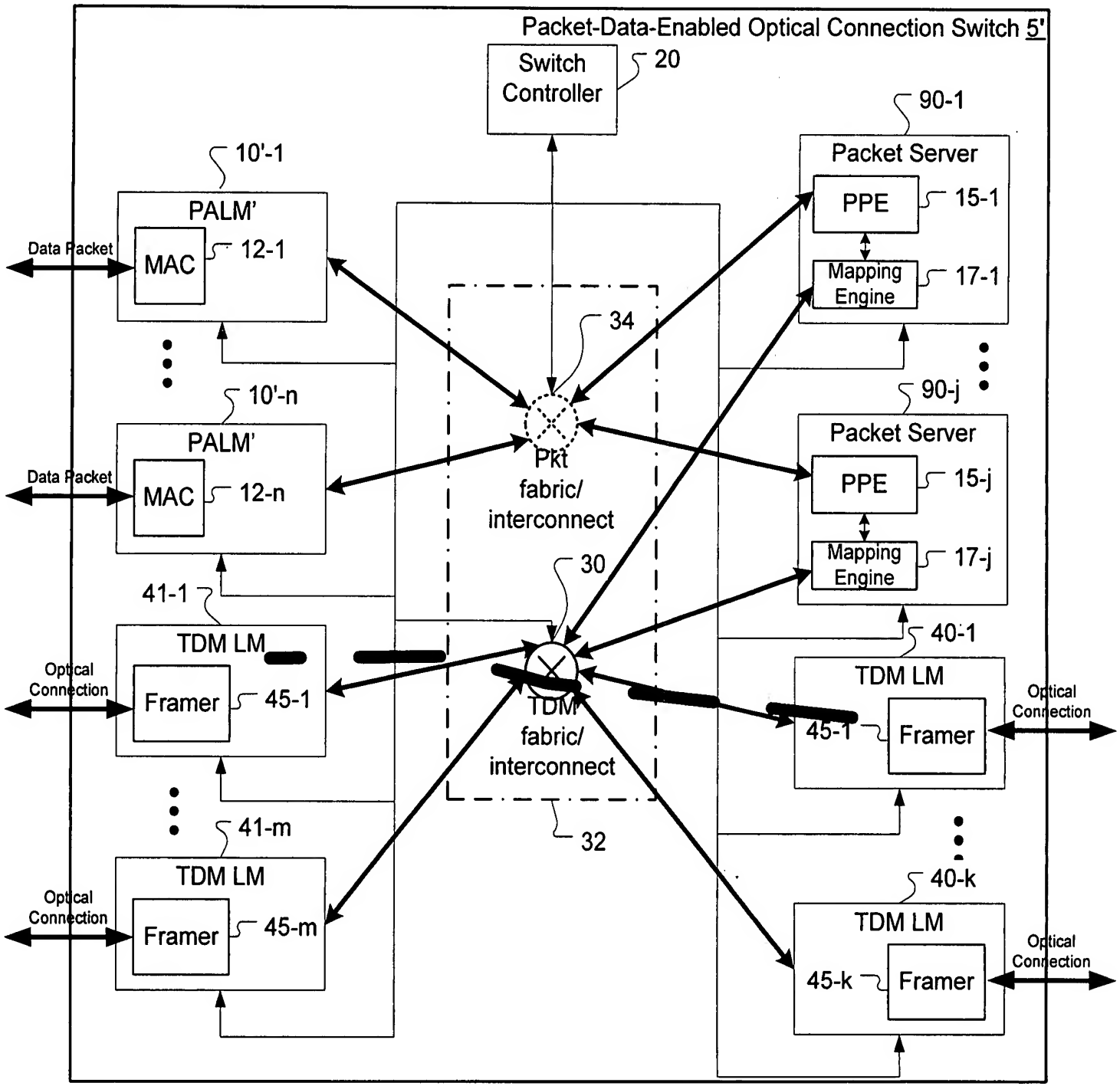

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
10'-1
PALM'
Data Packet
MAC
12-1
34
10'-n
PALM'
Data Packet
MAC
12-n
Pkt fabric/ interconnect
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
30
41-1
TDM LM
Optical Connection
Framer
45-1
TDM fabric/ interconnect
40-1
TDM LM
45-1
Framer
Optical Connection
41-m
TDM LM
Optical Connection
Framer
45-m
32
40-k
TDM LM
45-k
Framer
Optical Connection

Figure 12

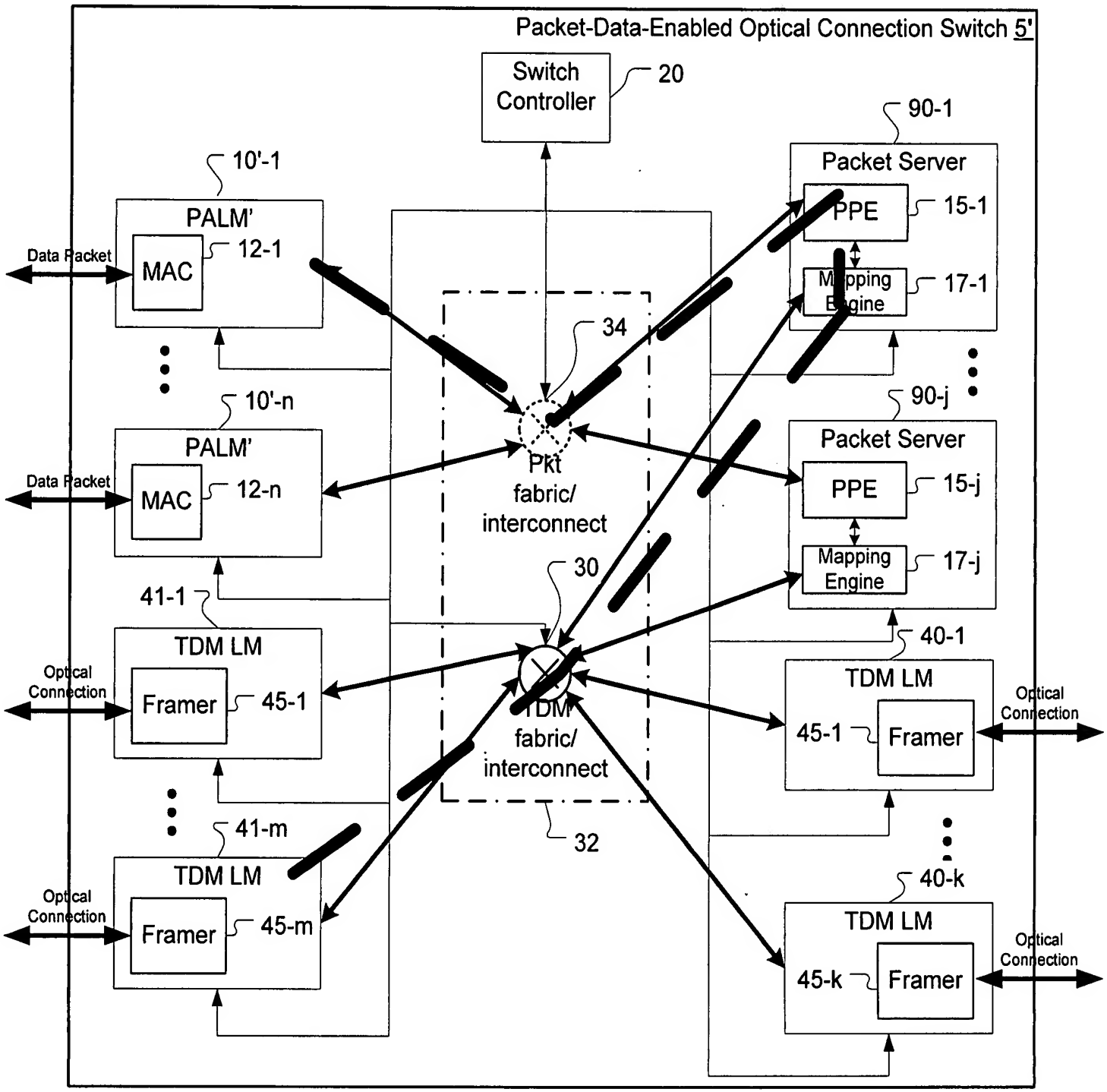

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
10'-1
PALM'
MAC
12-1
Data Packet
34
10'-n
PALM'
MAC
12-n
Data Packet
Pkt fabric/ interconnect
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
30
41-1
TDM LM
Framer
45-1
Optical Connection
TDM fabric/ interconnect
40-1
TDM LM
45-1
Framer
Optical Connection
41-m
TDM LM
Framer
45-m
Optical Connection
32
40-k
TDM LM
45-k
Framer
Optical Connection

Figure 13

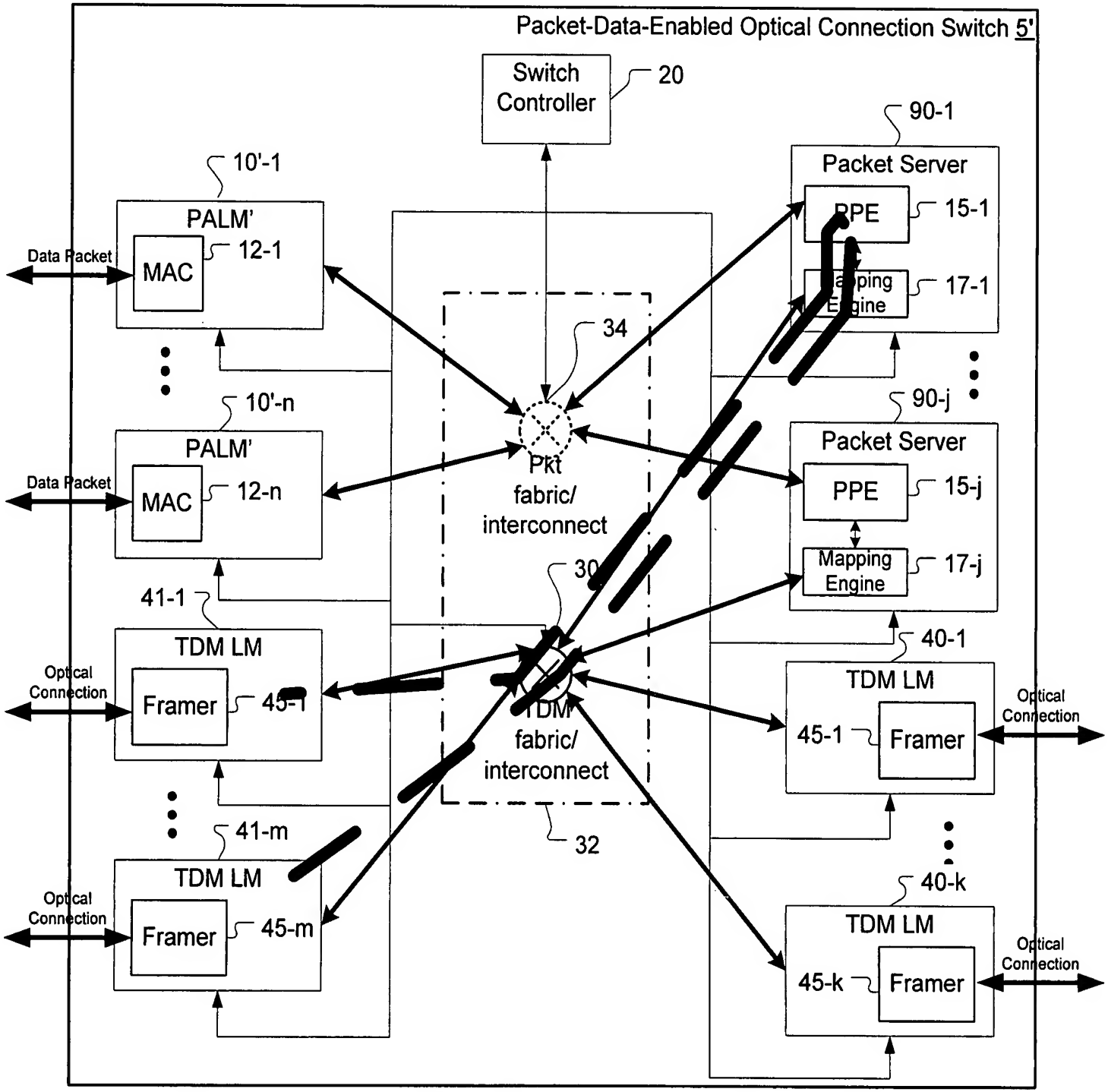

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
90-1
Packet Server
PPE
15-1
17-1
10'-1
PALM'
MAC
12-1
Data Packet
34
10'-n
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
Pkt fabric/ interconnect
30
41-1
TDM LM
Framer
45-1
Optical Connection
40-1
TDM LM
45-1
Framer
Optical Connection
TDM fabric/ interconnect
32
41-m
40-k
TDM LM
45-m
45-k

Figure 13a

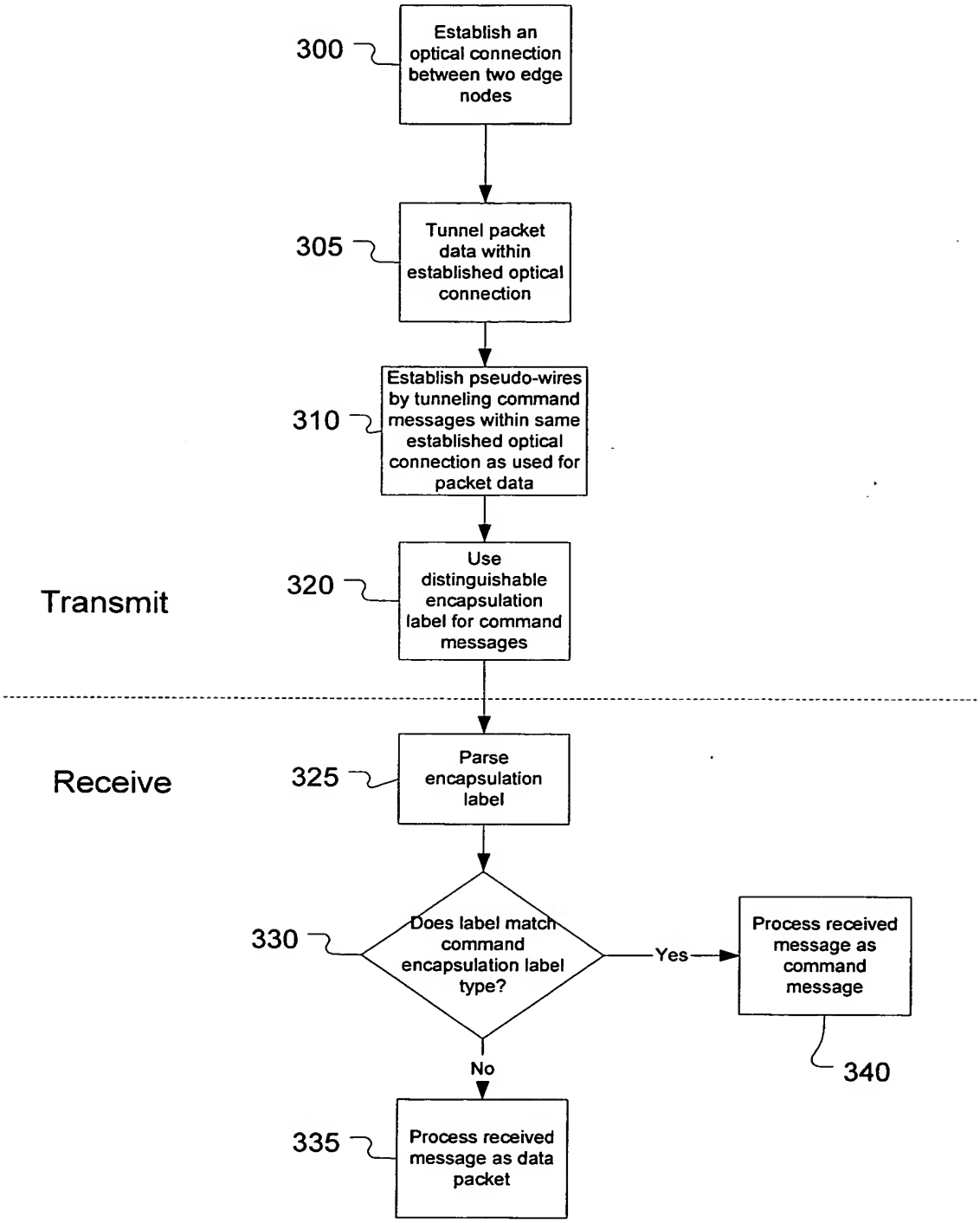

300
Establish an optical connection between two edge nodes
305
Tunnel packet data within established optical connection
310
Establish pseudo-wires by tunneling command messages within same established optical connection as used for packet data
Transmit
320
Use distinguishable encapsulation label for command messages
Receive
325
Parse encapsulation label
330
Does label match command encapsulation label type?
Yes
Process received message as command message
340
No
335
Process received message as data packet

Figure 14

Figure 15a

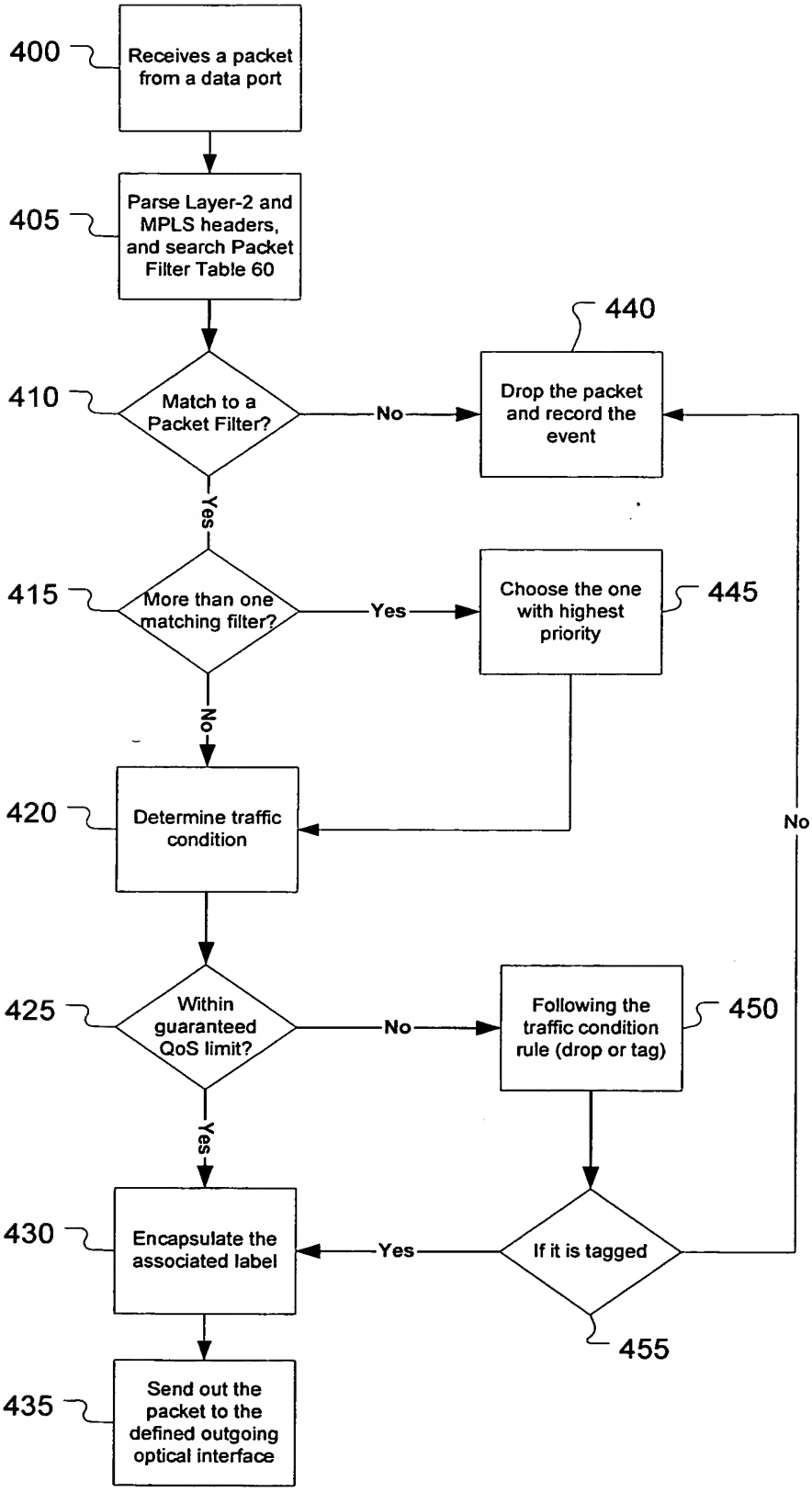

400
Receives a packet from a data port
405
Parse Layer-2 and MPLS headers, and search Packet Filter Table 60
410
Match to a Packet Filter?
No
440
Drop the packet and record the event
Yes
415
More than one matching filter?
Yes
Choose the one with highest priority
445
No
420
Determine traffic condition
425
Within guaranteed QoS limit?
No
Following the traffic condition rule (drop or tag)
450
Yes
430
Encapsulate the associated label
Yes
If it is tagged
No
455
435
Send out the packet to the defined outgoing optical interface

Figure 15b

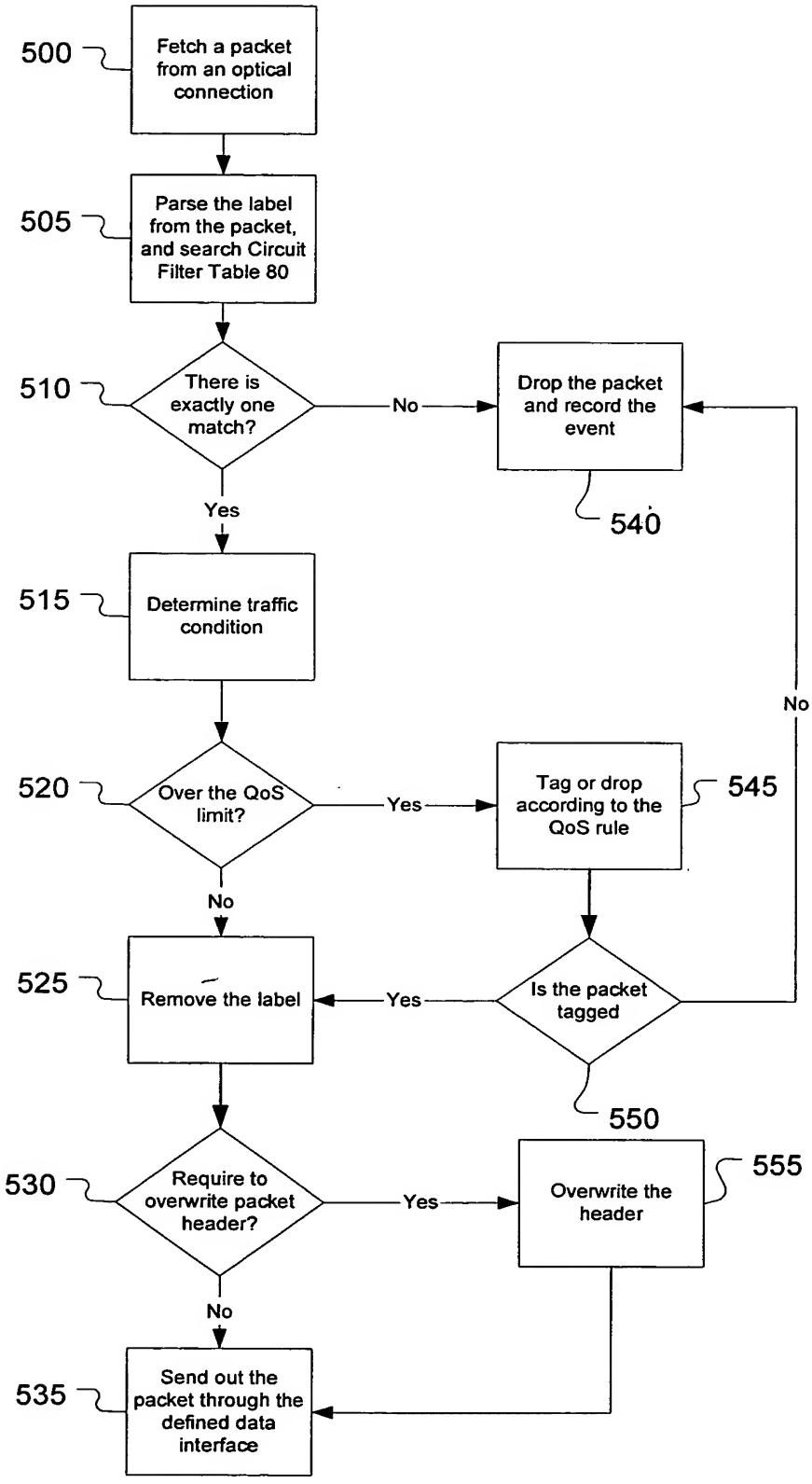
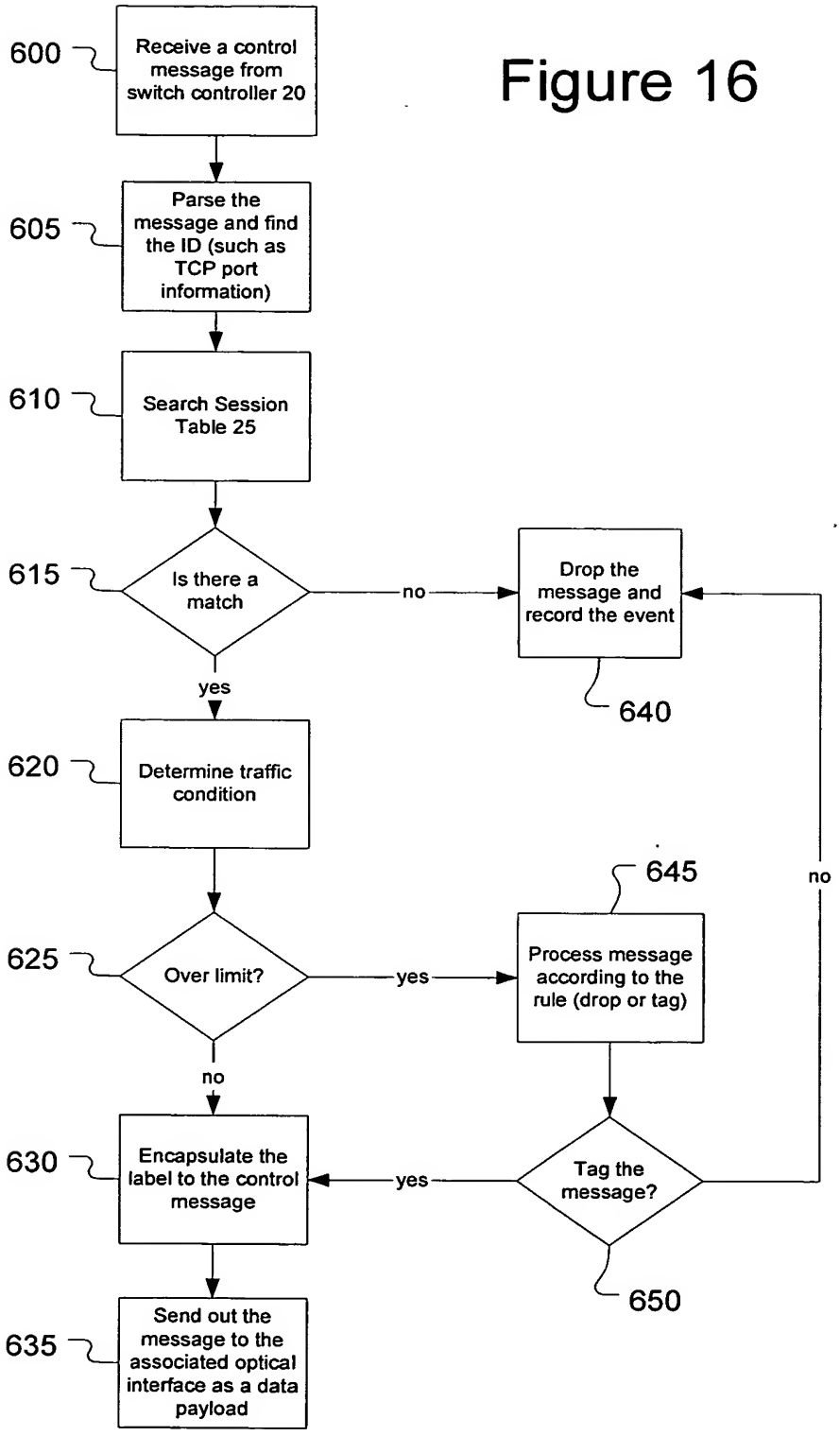

500
Fetch a packet from an optical connection
505
Parse the label from the packet, and search Circuit Filter Table 80
510
There is exactly one match?
No
Drop the packet and record the event
540
Yes
515
Determine traffic condition
520
Over the QoS limit?
Yes
Tag or drop according to the QoS rule
545
No
525
Remove the label
Yes
Is the packet tagged
No
550
530
Require to overwrite packet header?
Yes
Overwrite the header
555
No
535
Send out the packet through the defined data interface

Figure 16


600
Receive a control message from switch controller 20
605
Parse the message and find the ID (such as TCP port information)
610
Search Session Table 25
615
Is there a match
no
Drop the message and record the event
640
yes
620
Determine traffic condition
645
625
Over limit?
yes
Process message according to the rule (drop or tag)
no
630
Encapsulate the label to the control message
yes
Tag the message?
no
650
635
Send out the message to the associated optical interface as a data payload

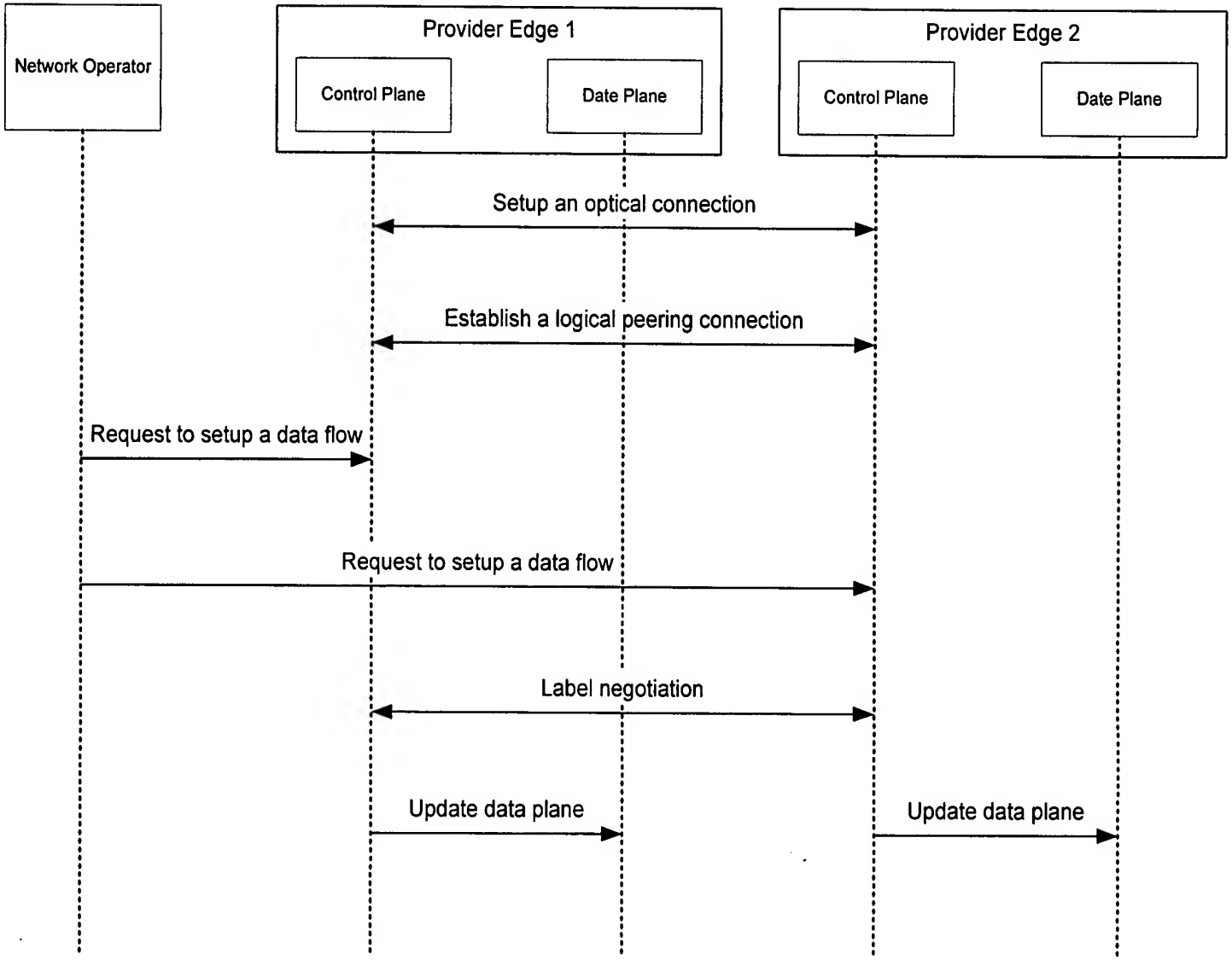

Network Operator
Provider Edge 1
Control Plane
Date Plane
Provider Edge 2
Control Plane
Date Plane
Setup an optical connection
Establish a logical peering connection
Request to setup a data flow
Request to setup a data flow
Label negotiation
Update data plane
Update data plane

Figure 17

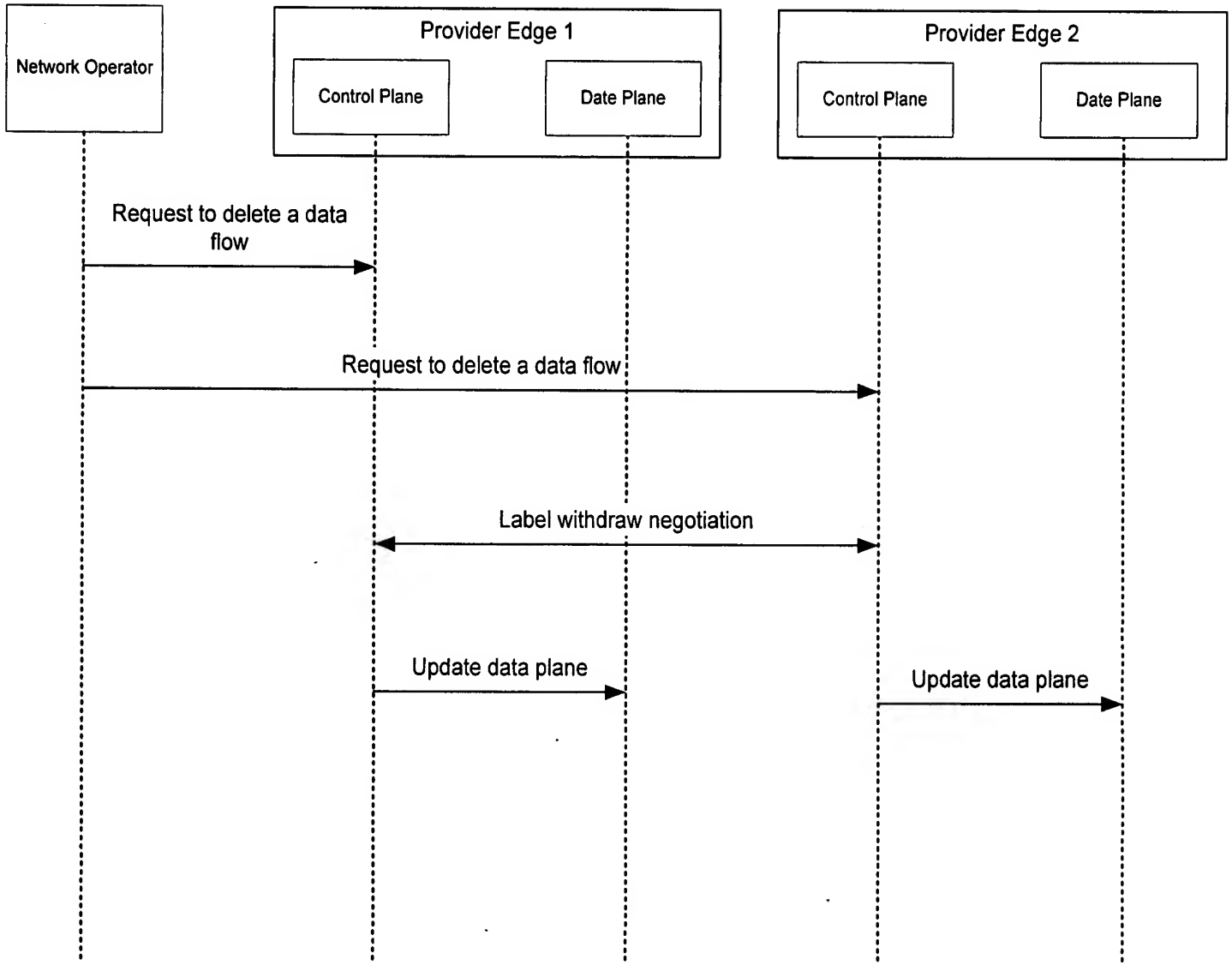

Network Operator
Provider Edge 1
Control Plane
Date Plane
Provider Edge 2
Control Plane
Date Plane
Request to delete a data flow
Request to delete a data flow
Label withdraw negotiation
Update data plane
Update data plane

Figure 18

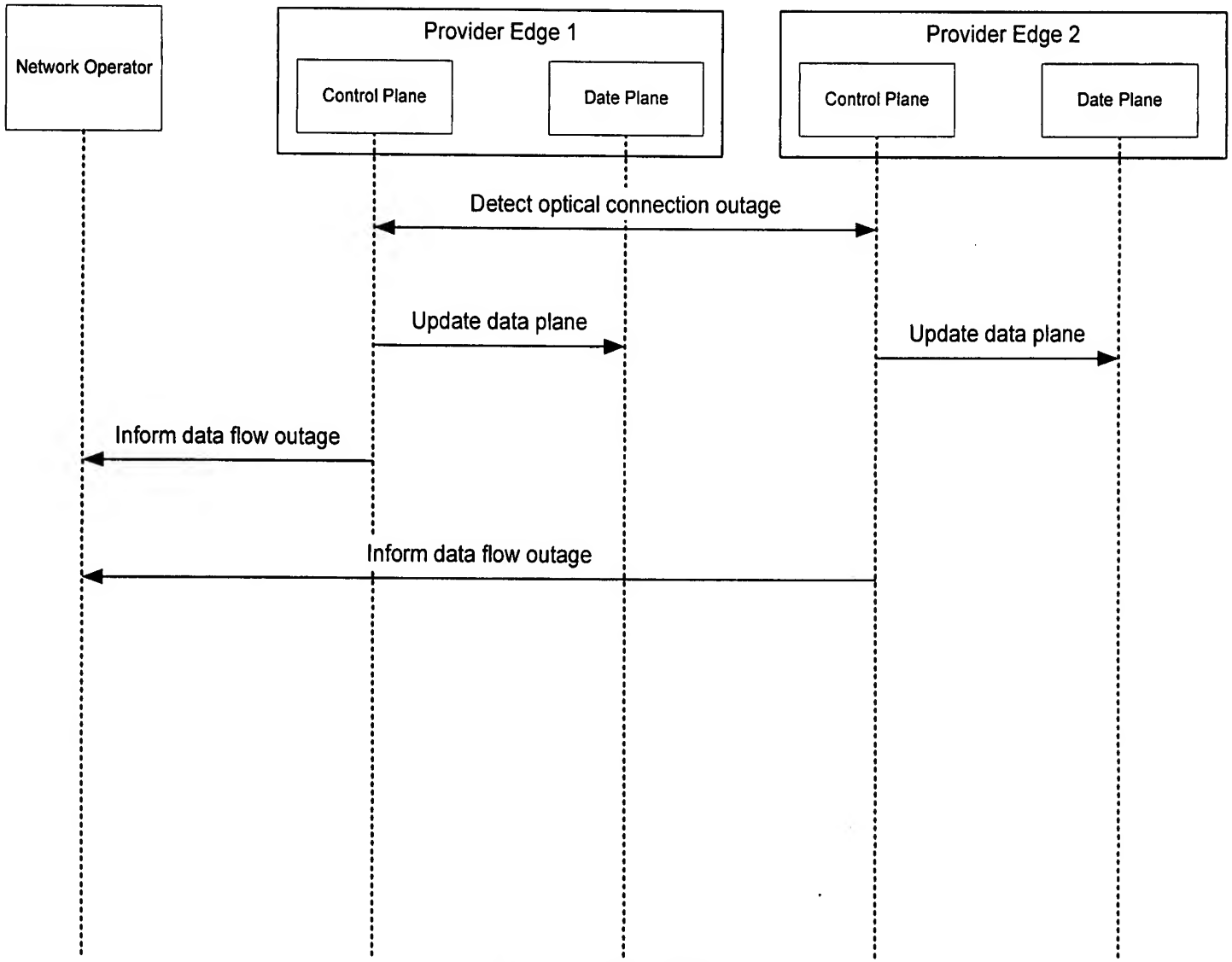

Network Operator
Provider Edge 1
Control Plane
Date Plane
Provider Edge 2
Control Plane
Date Plane
Detect optical connection outage
Update data plane
Update data plane
Inform data flow outage
Inform data flow outage

Figure 19

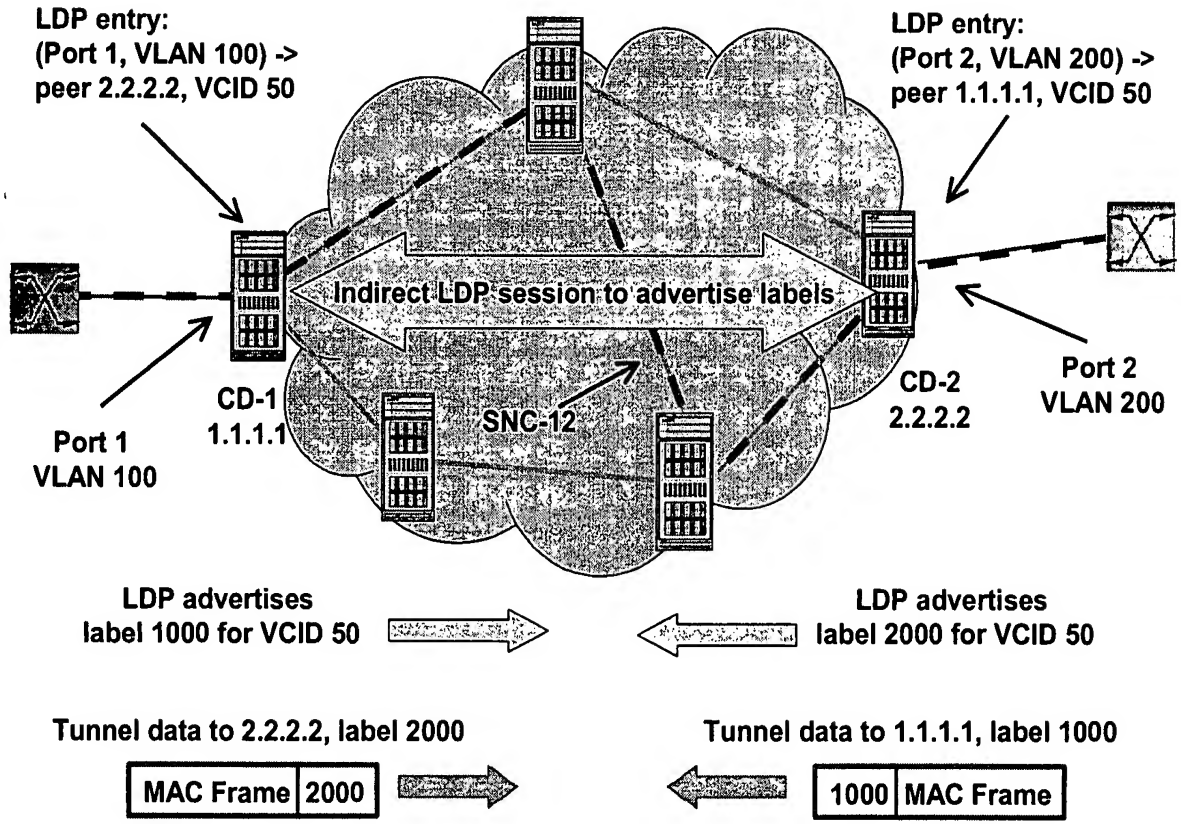

LDP entry:
(Port 1, VLAN 100) ->
peer 2.2.2.2, VCID 50
LDP entry:
(Port 2, VLAN 200) ->
peer 1.1.1.1, VCID 50
Indirect LDP session to advertise labels
CD-1
1.1.1.1
SNC-12
CD-2
2.2.2.2
Port 1
VLAN 100
Port 2
VLAN 200
LDP advertises
label 1000 for VCID 50
LDP advertises
label 2000 for VCID 50
Tunnel data to 2.2.2.2, label 2000
MAC Frame
2000
Tunnel data to 1.1.1.1, label 1000
1000
MAC Frame

Figure 20

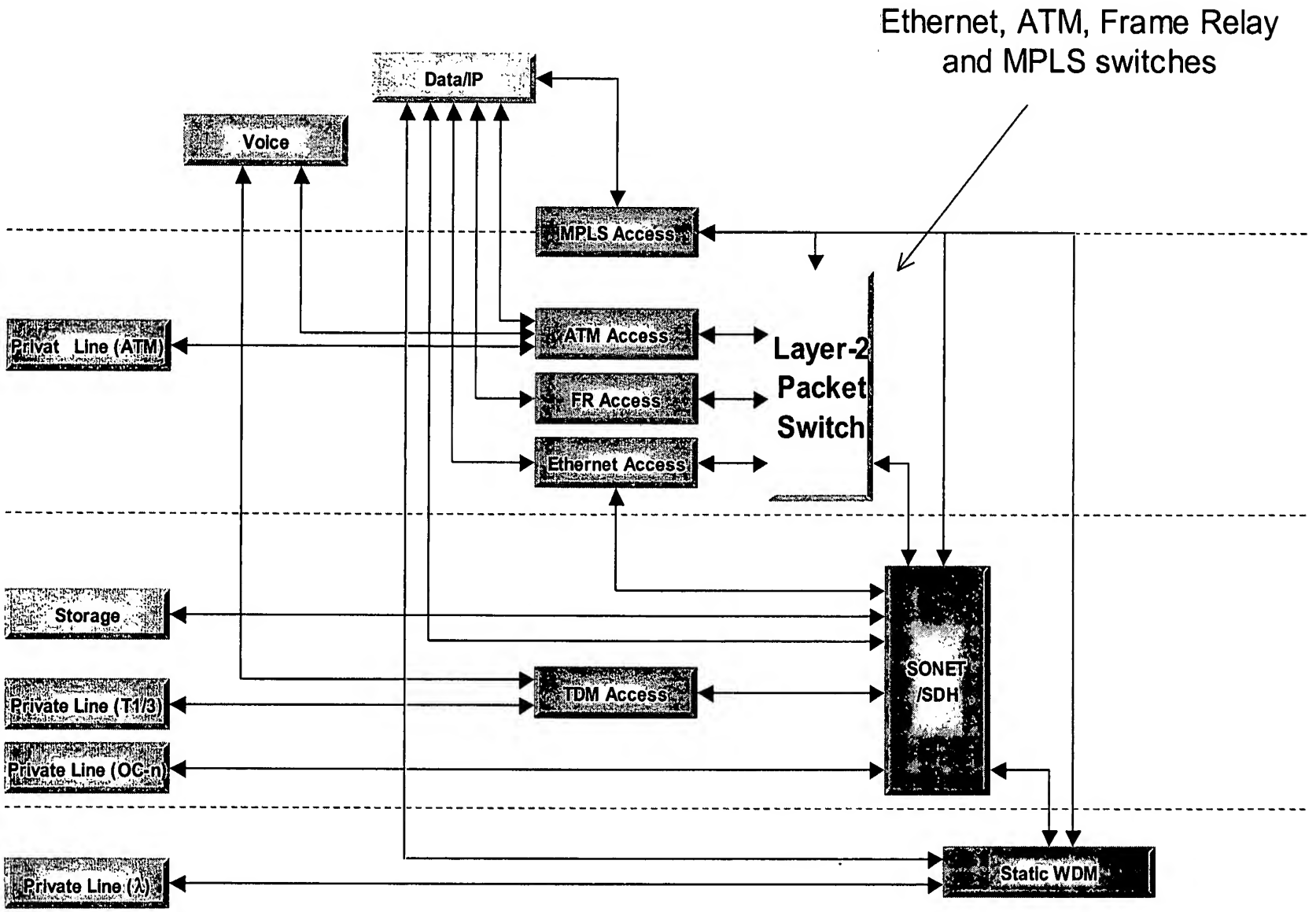



Figure 21
(Conventional)

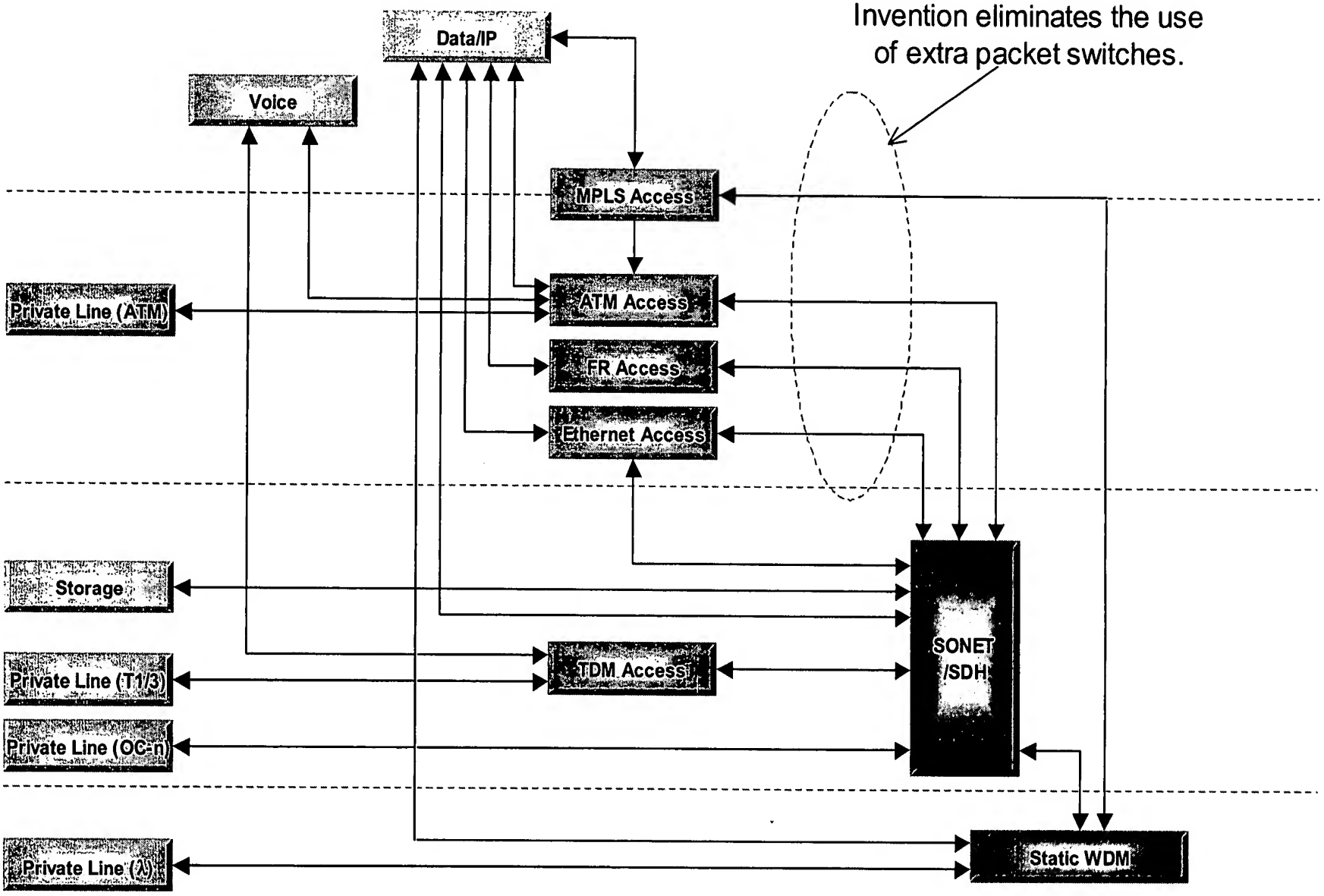

Invention eliminates the use of extra packet switches.
Data/IP
Voice
MPLS Access
ATM Access
FR Access
Ethernet Access
Private Line (ATM)
Storage
Private Line (T1/3)
Private Line (OC-n)
Private Line (λ)
TDM Access
SONET /SDH
Static WDM
Layer 0 Static WDM

Figure 22

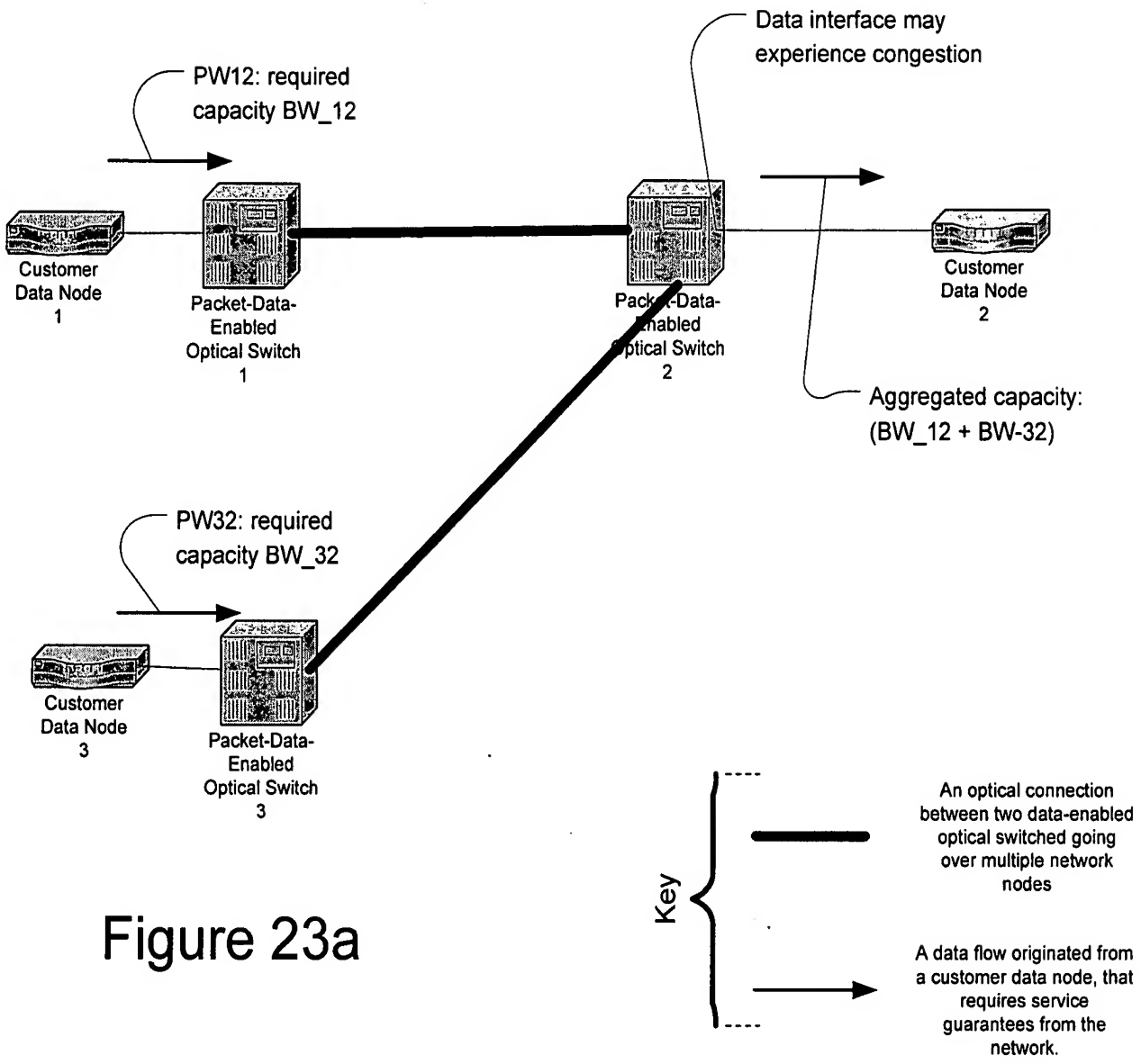

Data interface may experience congestion
PW12: required capacity BW_12
Customer Data Node 1
Packet-Data-Enabled Optical Switch 1
Packet-Data-Enabled Optical Switch 2
Customer Data Node 2
Aggregated capacity: (BW_12 + BW-32)
PW32: required capacity BW_32
Customer Data Node 3
Packet-Data-Enabled Optical Switch 3
Key
An optical connection between two data-enabled optical switched going over multiple network nodes
A data flow originated from a customer data node, that requires service guarantees from the network.

Figure 23a

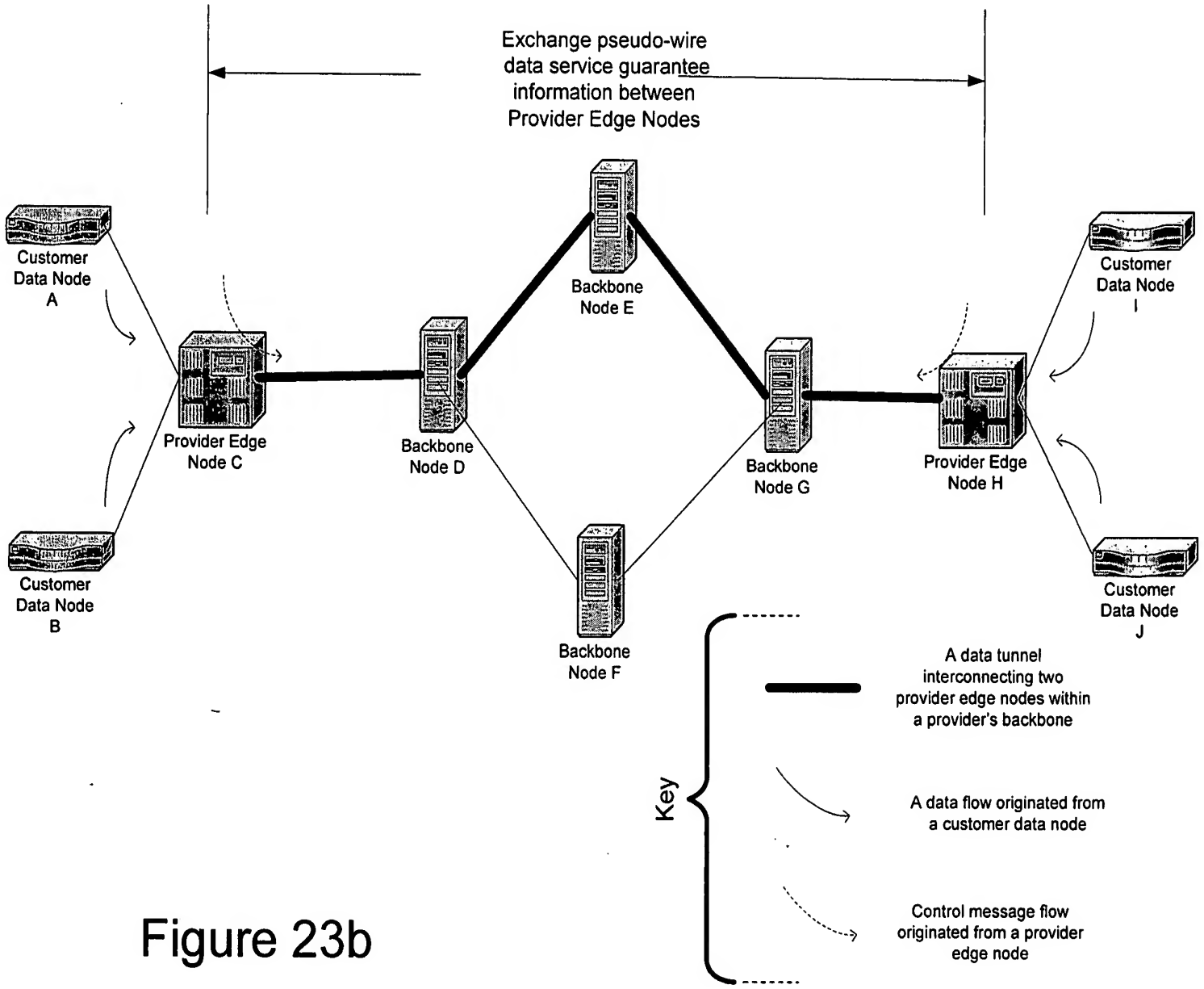

Exchange pseudo-wire data service guarantee information between Provider Edge Nodes
Customer Data Node A
Customer Data Node B
Provider Edge Node C
Backbone Node D
Backbone Node E
Backbone Node F
Backbone Node G
Provider Edge Node H
Customer Data Node I
Customer Data Node J
Key
A data tunnel interconnecting two provider edge nodes within a provider's backbone
A data flow originated from a customer data node
Control message flow originated from a provider edge node

Figure 23b

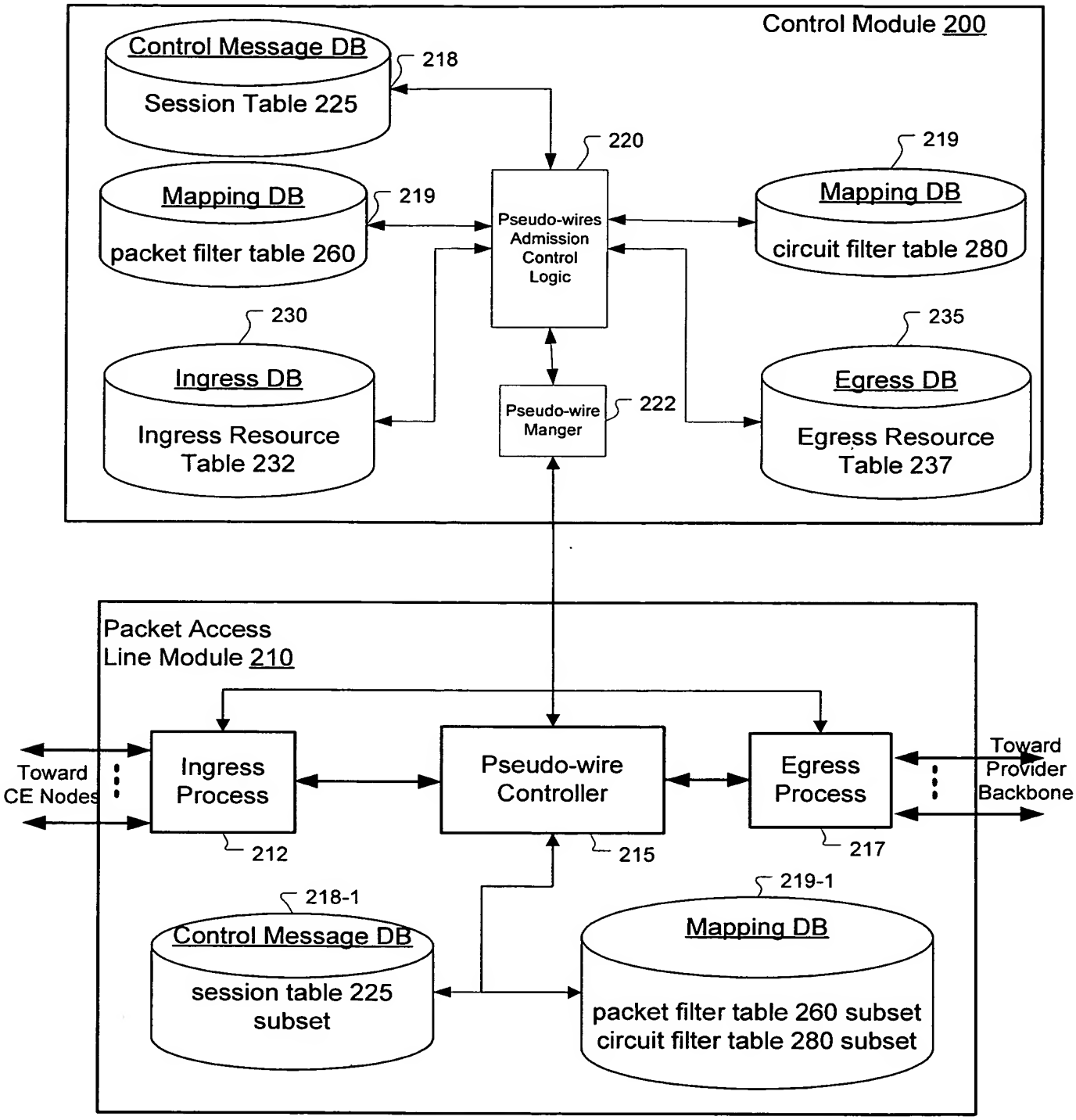

Control Module 200
Control Message DB
Session Table 225
218
220
219
Mapping DB
packet filter table 260
219
Pseudo-wires Admission Control Logic
Mapping DB
circuit filter table 280
230
235
Ingress DB
Ingress Resource Table 232
Pseudo-wire Manger
222
Egress DB
Egress Resource Table 237
Packet Access Line Module 210
Toward CE Nodes
Ingress Process
Pseudo-wire Controller
Egress Process
Toward Provider Backbone
212
215
217
218-1
219-1
Control Message DB
session table 225 subset
Mapping DB
packet filter table 260 subset
circuit filter table 280 subset

Figure 24

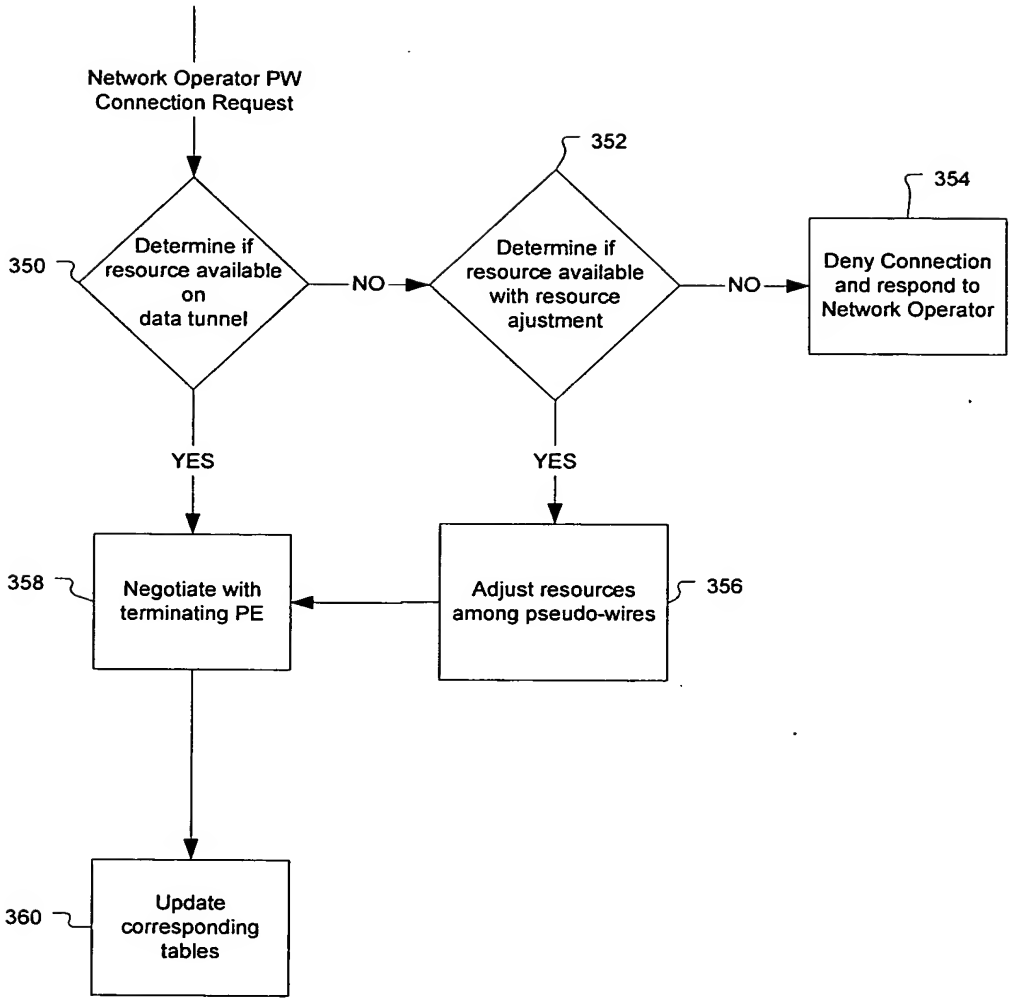

Network Operator PW Connection Request
350
Determine if resource available on data tunnel
NO
352
Determine if resource available with resource ajustment
NO
354
Deny Connection and respond to Network Operator
YES
YES
358
Negotiate with terminating PE
Adjust resources among pseudo-wires
356
360
Update corresponding tables

Figure 25a

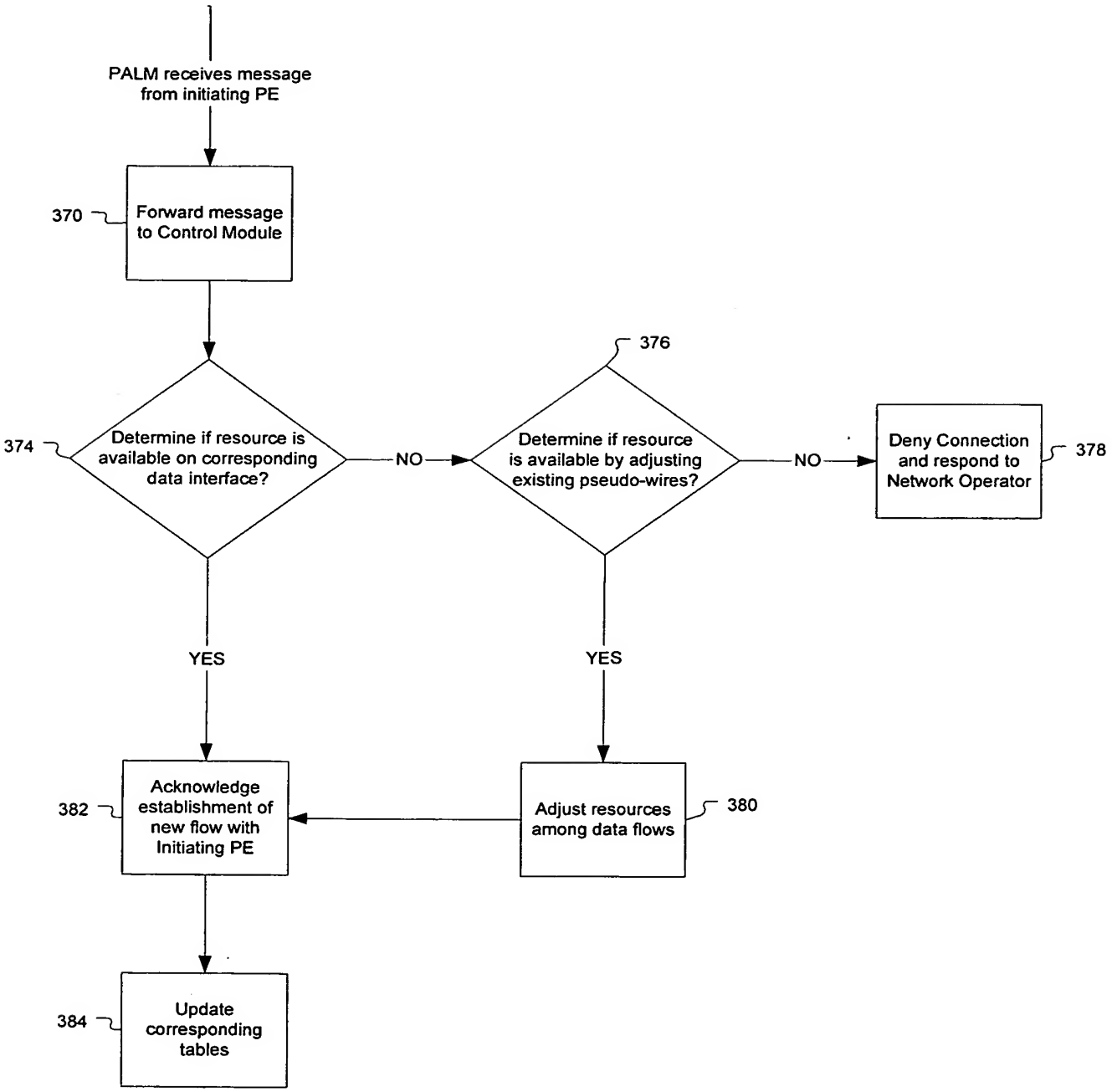

PALM receives message from initiating PE
370
Forward message to Control Module
374
Determine if resource is available on corresponding data interface?
NO
376
Determine if resource is available by adjusting existing pseudo-wires?
NO
Deny Connection and respond to Network Operator
378
YES
YES
382
Acknowledge establishment of new flow with Initiating PE
Adjust resources among data flows
380
384
Update corresponding tables

Figure 25b

260

| PACKET FILTER TABLE | | | | | | |
|---|---|---|---|---|---|---|
| PACKET FILTER (DATA INTERFACE, LABEL) | DATA TUNNEL | ENCAPSULATION LABEL | CIR | CLASS | SETUP PRIORITY | HOLDING PRIORITY |
| PACKET FILTER-1 (PORT 1, ETHERNET VLAN 100) | SONET VCG NUMBER 3 | MPLS LABEL 10000 | 50 Mb/Sec | AF-1 | 3 | 5 |
| PACKET FILTER-2 (PORT 5, ATM VCI/VPI 12/45) | ROUTER INTERFACE 5 | MPLS LABEL 20000 | 8 Mb/Sec | EF | 3 | 5 |
| PACKET FILTER-3 (PORT 2, FR DLCI 900) | SONET VCG NUMBER 3 | MPLS LABEL 500 | 10 Mb/Sec | AF-1 | 3 | 5 |
| PACKET FILTER-4 (PORT 10) | ETHERNET INTERFACE 12 | MPLS LABEL 50001 | 1 Gb/Sec | AF-3 | 5 | 5 |

Figure 26

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| CIRCUIT FILTER TABLE | | | | | |
|---|---|---|---|---|---|
| CIRCUIT FILTER (DATA TUNNEL, LABEL) | OUTGOING DATA INTERFACE | CIR | CLASS | SETUP PRIORITY | HOLDING PRIORITY |
| CIRCUIT FILTER-1 (SONET VCG 3, LABEL 20000) | DATA PORT 1 | 50 Mb/Sec | AF-1 | 3 | 3 |
| CIRCUIT FILTER-2 (SONET VCG 3, LABEL 20001) | DATA PORT 2 | 8 Mb/Sec | EF | 3 | 3 |
| CIRCUIT FILTER-3 (OPTICAL INTERFACE 1, LABEL 300) | DATA PORT 10 | 10 Gb/Sec | AF-3 | 3 | 3 |
| CIRCUIT FILTER-4 (SONET VCG 5, LABEL 12000) | DATA PORT 1 | 100 Mb/Sec | AF-1 | 1 | 1 |
| CIRCUIT FILTER-5 (SONET VCG 3, LABEL 3) | DATA PORT 2 | 1 Gb/Sec | AF-1 | 5 | 5 |

Figure 27

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| SESSION TABLE | | | | |
|---|---|---|---|---|
| SESSION (CONTROL MESSAGE ID) | OUTGOING DATA TUNNEL | ENCAPSULATION LABEL | CIR | CLASS |
| SESSION 1 (TCP SRC PORT 1345) | SONET VCG NUMBER 3 | MPLS LABEL 3 | 1 Mb/Sec | EF |
| SESSION 2 (TCP SRC PORT 3456) | MPLS LSP 8 | MPLS LABEL 3 | 2 Mb/Sec | EF |
| SESSION 3 (TCP SRC PORT 1998) | OPTICAL INTERFACE 1 | MPLS LABEL 10000 | N/A | EF |

Figure 28

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| INGRESS RESOURCE TABLE | | | | | |
|---|---|---|---|---|---|
| DATA TUNNEL | PHYSICAL BANDWIDTH | AVAILABLE TOTAL BANDWIDTH | AVAILABLE BANDWIDTH CLASS 1 | AVAILABLE BANDWIDTH CLASS ... | AVAILABLE BANDWIDTH CLASS N |
| MPLS LSP with label 45 | 80 Mb/Sec | 70 Mb/Sec | 20 Mb/sec | ... | 30 Mb/sec |
| SONET VCG 4 | 100 Mb/Sec | 50 Mb/Sec | 50 Mb/Sec | ... | 0 |
| DEDICATED POS CONNECTION | 45 Mb/Sec | 12 Mb/Sec | 1.5 Mb/src | ... | 3.0 Mb/src |

Figure 29a

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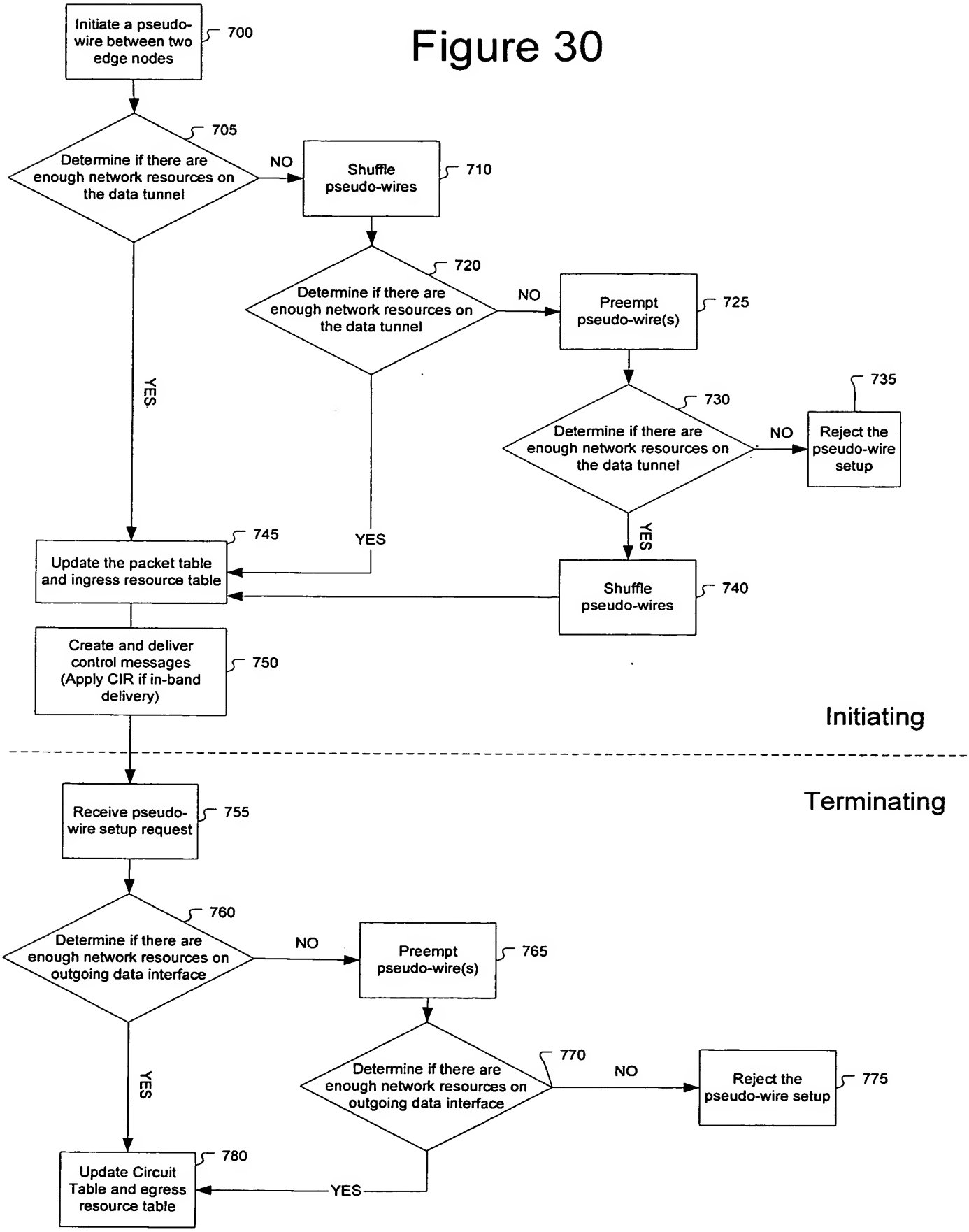
| EGRESS RESOURCE TABLE | | | | | |
|---|---|---|---|---|---|
| DATA INTERFACE | PHYSICAL BANDWIDTH | AVAILABLE TOTAL BANDWIDTH | AVAILABLE BANDWIDTH CLASS 1 | AVAILABLE BANDWIDTH CLASS ... | AVAILABLE BANDWIDTH CLASS N |
| ATM Interface | 150 Mb/Sec | 70 Mb/Sec | 20 Mb/sec | ... | 30 Mb/sec |
| Ethernet Interface | 100 Mb/Sec | 50 Mb/Sec | 50 Mb/Sec | ... | 0 |
| DS3 Interface | 45 Mb/Sec | 12 Mb/Sec | 1.5 Mb/src | ... | 3.0 Mb/src |

Figure 29b

# Figure 30


Initiate a pseudo-wire between two edge nodes
700
Determine if there are enough network resources on the data tunnel
705
NO
Shuffle pseudo-wires
710
YES
Determine if there are enough network resources on the data tunnel
720
NO
Preempt pseudo-wire(s)
725
Determine if there are enough network resources on the data tunnel
730
NO
Reject the pseudo-wire setup
735
YES
YES
Update the packet table and ingress resource table
745
Shuffle pseudo-wires
740
Create and deliver control messages (Apply CIR if in-band delivery)
750
Initiating
Terminating
Receive pseudo-wire setup request
755
Determine if there are enough network resources on outgoing data interface
760
NO
Preempt pseudo-wire(s)
765
YES
Determine if there are enough network resources on outgoing data interface
770
NO
Reject the pseudo-wire setup
775
Update Circuit Table and egress resource table
780
YES

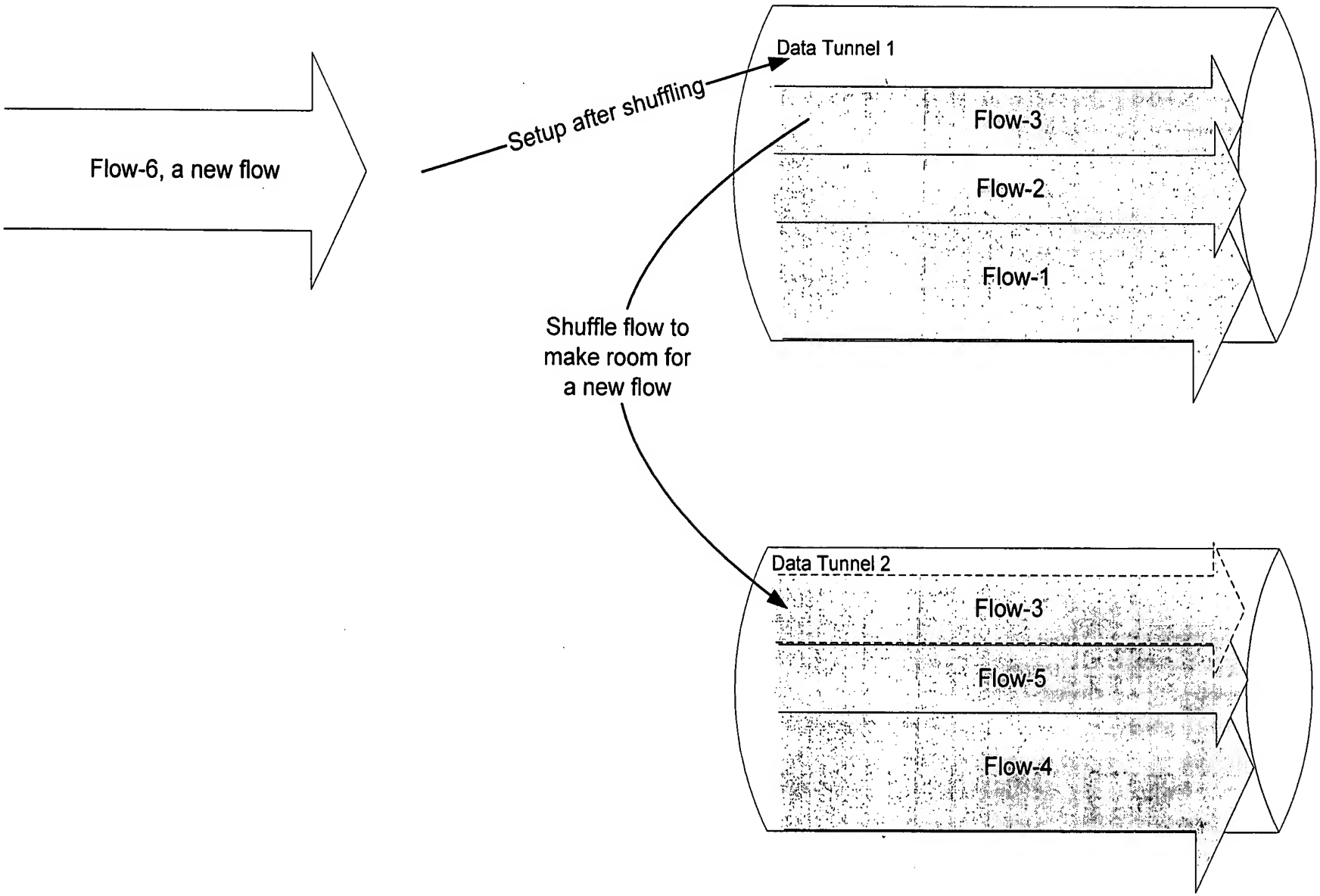

Flow-6, a new flow
Setup after shuffling
Data Tunnel 1
Flow-3
Flow-2
Flow-1
Shuffle flow to
make room for
a new flow
Data Tunnel 2
Flow-3
Flow-5
Flow-4

Figure 31

Figure 32

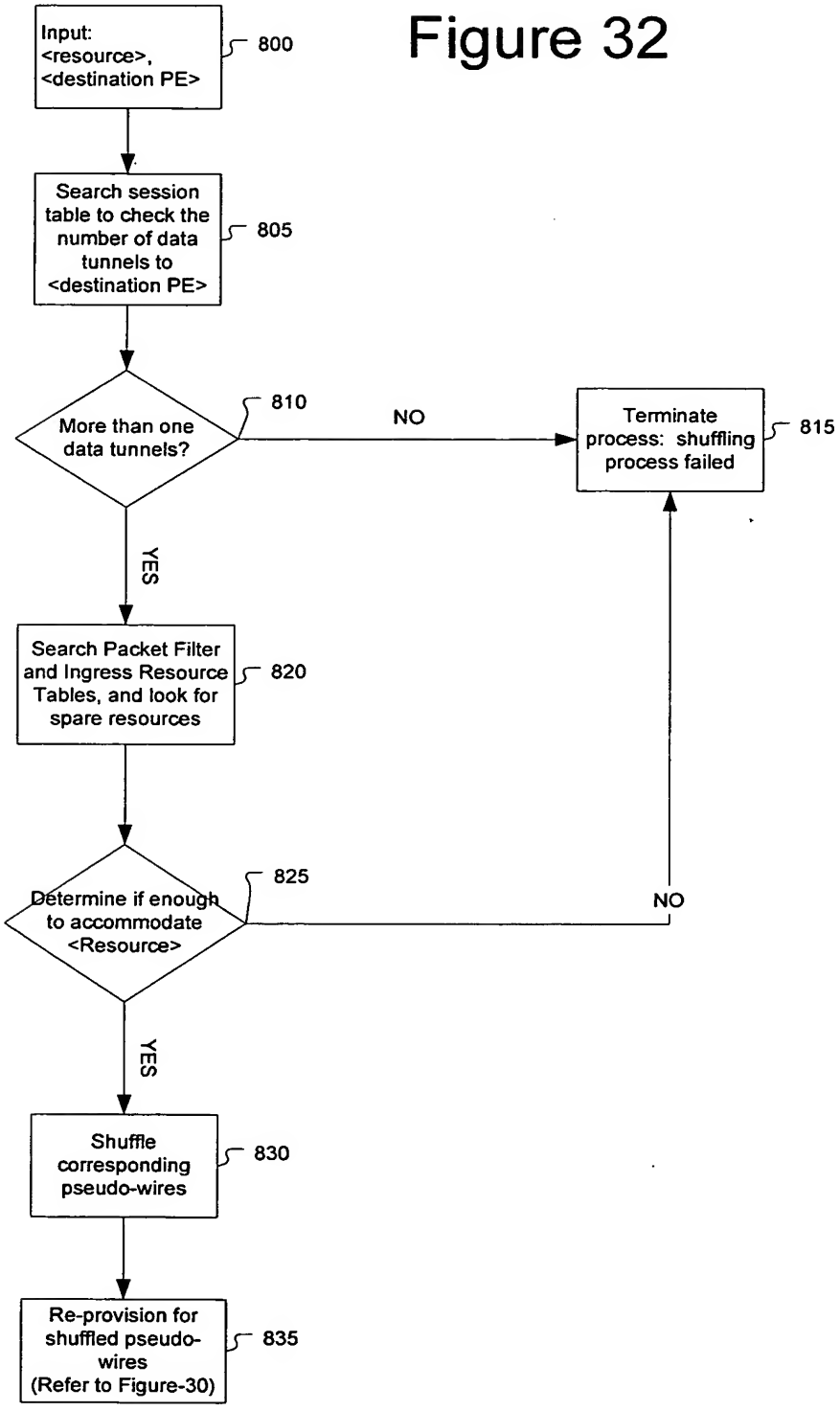
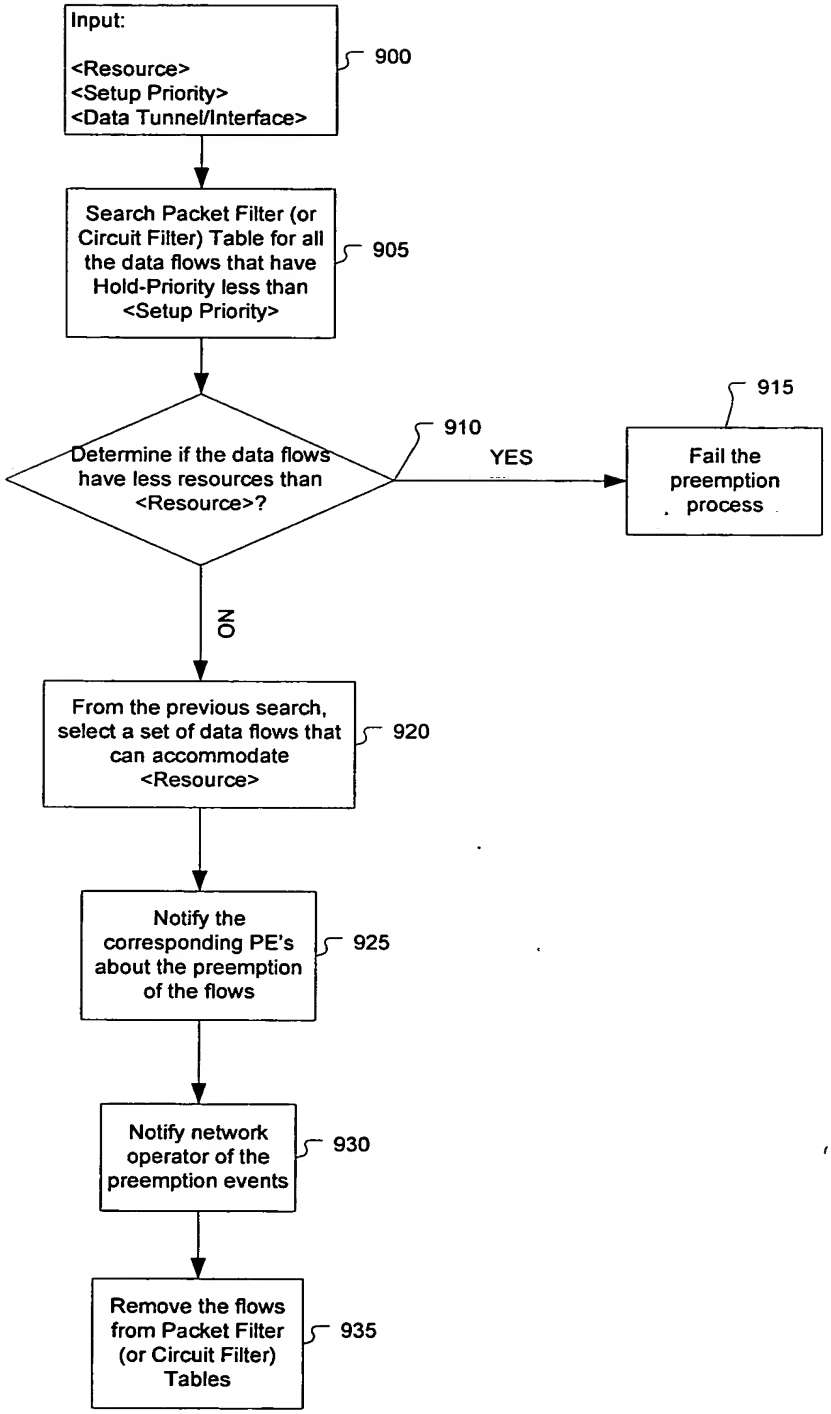

Input: <resource>, <destination PE>
800
Search session table to check the number of data tunnels to <destination PE>
805
More than one data tunnels?
810
NO
Terminate process: shuffling process failed
815
YES
Search Packet Filter and Ingress Resource Tables, and look for spare resources
820
Determine if enough to accommodate <Resource>
825
NO
YES
Shuffle corresponding pseudo-wires
830
Re-provision for shuffled pseudo-wires (Refer to Figure-30)
835

Figure 33


Input:
<Resource>
<Setup Priority>
<Data Tunnel/Interface>
900
Search Packet Filter (or Circuit Filter) Table for all the data flows that have Hold-Priority less than <Setup Priority>
905
Determine if the data flows have less resources than <Resource>?
910
YES
915
Fail the preemption process
NO
From the previous search, select a set of data flows that can accommodate <Resource>
920
Notify the corresponding PE's about the preemption of the flows
925
Notify network operator of the preemption events
930
Remove the flows from Packet Filter (or Circuit Filter) Tables
935

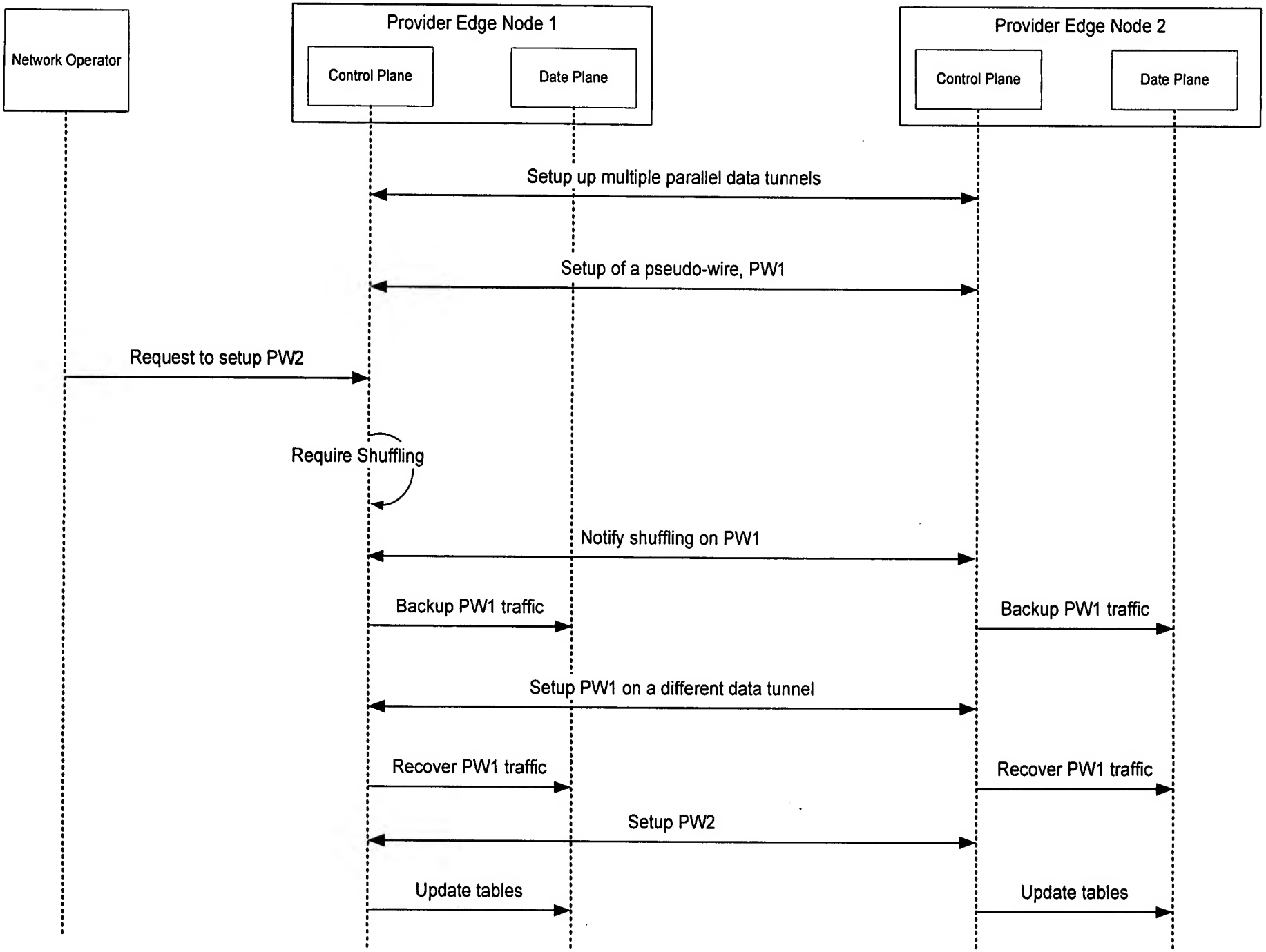

Network Operator
Provider Edge Node 1
Control Plane
Date Plane
Provider Edge Node 2
Control Plane
Date Plane
Setup up multiple parallel data tunnels
Setup of a pseudo-wire, PW1
Request to setup PW2
Require Shuffling
Notify shuffling on PW1
Backup PW1 traffic
Backup PW1 traffic
Setup PW1 on a different data tunnel
Recover PW1 traffic
Recover PW1 traffic
Setup PW2
Update tables
Update tables

Figure 34

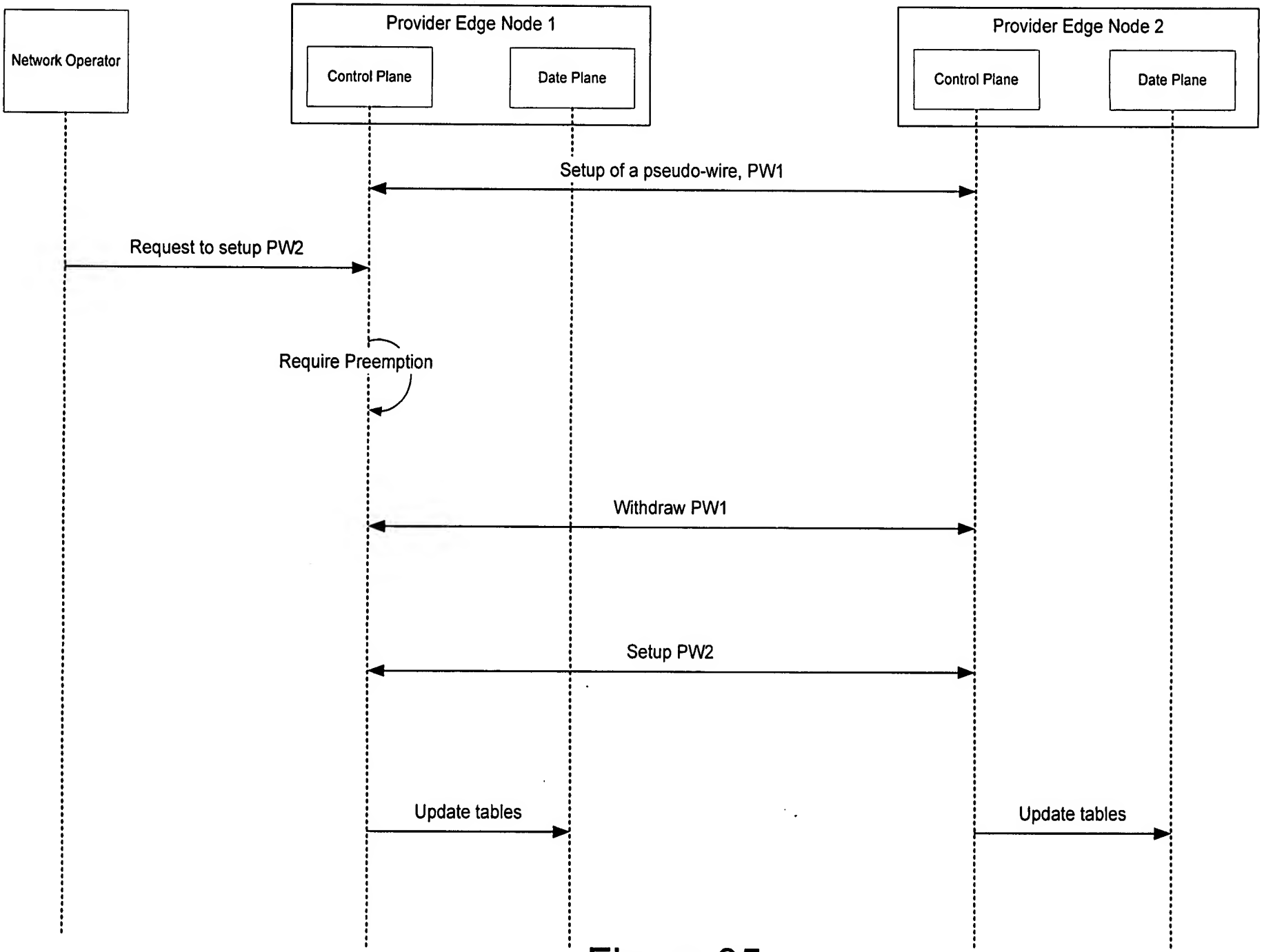

Network Operator
Provider Edge Node 1
Control Plane
Date Plane
Provider Edge Node 2
Control Plane
Date Plane
Setup of a pseudo-wire, PW1
Request to setup PW2
Require Preemption
Withdraw PW1
Setup PW2
Update tables
Update tables

Figure 35

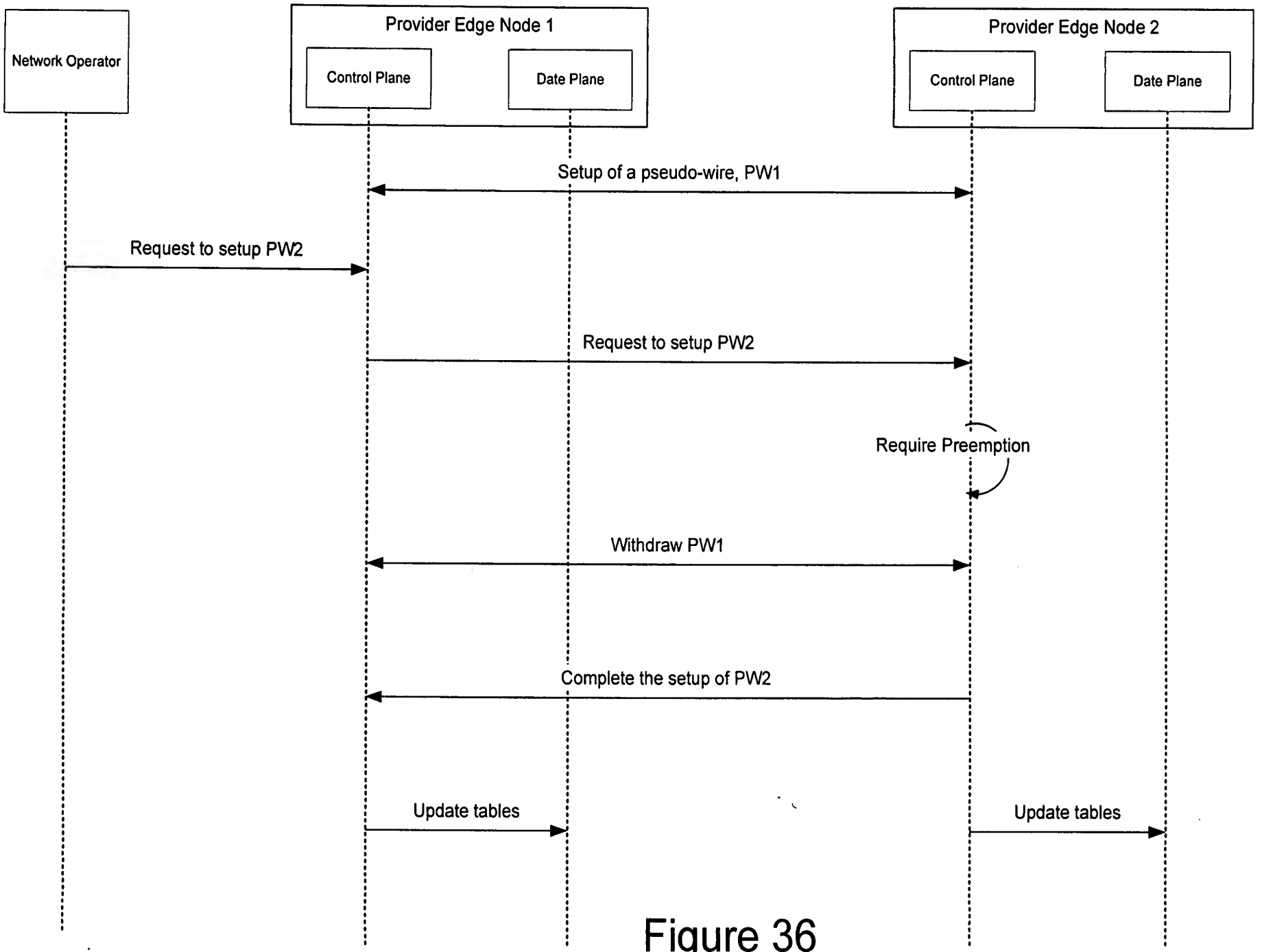

Network Operator
Provider Edge Node 1
Control Plane
Date Plane
Provider Edge Node 2
Control Plane
Date Plane
Setup of a pseudo-wire, PW1
Request to setup PW2
Request to setup PW2
Require Preemption
Withdraw PW1
Complete the setup of PW2
Update tables
Update tables

Figure 36